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Metals in Eggs of the California Least Tern in Southern California

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Abstract.—Eggs of the endangered California Least Tern (*Sterna antillarum browni*) which nests in coastal southern California were analyzed for 10 heavy metals. Mean values ranged from 12,241 ng/gm (ppb) for zinc to 70 (ppb) in cadmium; concentrations of barium, mercury, and tin were below detection limits. Levels of selenium (761 ppb) and lead (110 ppb) tentatively recorded were thought to warrant further more detailed study as they may be approaching levels which could impair reproductive success in this species.

The ability of pollutants to enter the food chain has been considered by numerous authors. Once within the body of an organism they can be excreted or stored in tissues and thus be available for further bioaccumulation or magnification to potentially lethal levels higher in the food chain. Female birds may also sequester pollutants such as organochlorines and heavy metals in their eggs with possible adverse effects upon the embryo (Burger and Gochfeld 1988). These possibilities are of particular concern when dealing with endangered species where all variables which may be responsible for their decline must be identified and considered in recovery plans (Pattee et al. 1990).

The California Least Tern, *Sterna antillarum browni*, is an endangered species of bird that occurs primarily in Southern California (Massey 1989) where it nests on coastal sandy beaches, frequently adjacent to rivers or channel mouths (Massey 1974, 1981). Its population decline in recent decades has been presumed to have been largely due to the destruction of nesting habitat by the rapidly increasing human population in its nesting range (California Least Tern Recovery Team 1980). However, the highly urbanized environment adjacent to their nesting areas in southern California also provides ample opportunity for pollutants to enter the local aquatic food chain and impact the California Least Tern. Recent studies have indicated that potentially dangerous levels of organochlorines, especially DDT and its metabolites (Boardman 1988) and lead (Boardman and Collins 1992) are present in California Least Tern eggs and feathers respectively. The data presented here represent a preliminary analysis of a variety of heavy metals recovered from the eggs of this tern.

Materials and Methods

A total of 15 eggs which were deserted or failed to hatch were removed from two colonies between May and August 1988. Ten eggs (no's 121-169; Table 1) were from Venice Beach, Los Angeles County and 5 eggs (no's 17-31; Table 1) were from the Naval Air Station, North Island, San Diego County. Detailed

Table 1. Metal^{1,2} in California Least Tern eggs.

Sample no.	Cr	Ni	Cu	Zn	Se	Cd	Pb
121	228	170	1144	11,954	140	131	175
135a	452	138	1462	19,400	487	92	0
135b	360	430	2260	2103	335	89	0
139a	392	86	1339	9530	351	138	408
139b	464	329	3800	19,031	680	198	63
143	242	123	1595	8100	404	251	0
146	281	181	1055	12,988	890	24	0
147	347	198	1092	11,236	240	35	0
155	345	308	1856	10,972	2394	68	120
169	236	69	1356	6903	1413	11	0
SD17	836	631	1078	14,080	987	29	0
SD17-2	510	522	1356	17,659	231	34	0
SD19	254	99	952	4784	145	33	77
SD19-2	260	105	1221	19,786	1090	8	744
SD31	269	189	1463	15,093	1634	16	92
Mean	365.1	238.5	1535.3	12,241.3	761.4	77.1	111.9
(SD)	(153)	(165)	(688)	(5226)	(627)	(71)	(199)
SRM-Oyster	85.5%	96.5%	90.7%	84.0%	194.3%	111.6%	152.2%

¹ Metal concentrations are given in ng/g (ppb) wet eight of whole egg homogenates.² Barium, mercury and tin concentrations were below detection limits on all samples.

accounts of these sites are presented elsewhere (California Least Tern Recovery Team 1980). Metal analyses were carried out by the Molecular Ecology Institute (MEI), California State University, Long Beach.

The 10 samples from Venice Beach had been removed from the shell and stored in glass containers having metal screw-type lids prior to analysis and the potential therefore exists for sample metal contamination from the shipping containers. The five samples from North Island were received as whole eggs. All samples were stored at -80°C until processing. Each sample was then thawed to room temperature for approximately 15 minutes and, where necessary, egg tissue was removed from the shell. Egg tissues were individually homogenized using a teflon spatula and a 1 g wet weight aliquot transferred to an individual polypropylene digestion container. The remaining tissue and shell samples were transferred to low temperature storage.

Samples were digested using a CEM microwave digestion system with the following protocol: 1 g wet weight sample in 10 ml concentrated nitric acid (redistilled "low" metal acid) followed by one hour digestion duration at a mean power setting of 300 Watts. In addition to the 15 Least Tern samples, three processing blank samples, and two Standard Reference Material (SRM) oyster tissue samples were processed. Resulting digests were quantitatively transferred and brought up to 200 ml final volume using 18 Mega-ohm distilled deionized water. Sample digests were spiked with an internal uranium standard to yield a final concentration of 100 ng/g during sample analysis. A 4 ml aliquot was analyzed for the following trace metals: chromium, nickel, copper, zinc, selenium, cadmium, tin, barium, mercury, and lead.

Samples were analyzed using a VG PlasmaQuad Inductively Coupled Plasma Mass Spectrometer (ICP/MS). In addition to the standard ICP/MS configuration, the instrument was equipped with a water-cooled spray chamber and ETP discrete diode detector to optimize sensitivity and stability and minimize background noise. Two reagent blanks and one aqueous metal sensitivity standard (100 ppb) were analyzed per approximately 10 test samples. All test samples, standard reference materials, procedural, and reagent blanks were analyzed at the same time on the ICP/MS for an identical suite of metal isotopes. Samples were quantified from standard curves generated from the analysis of five aqueous metal standards including 0.1, 1.0, 10.0, 100.0, and 1000.0 ng/g metal.

"Clean technique" methodology was followed for all aspects of sample handling, processing, digestion, homogenization, and final analyses for trace metals which incorporate precautions to minimize contamination of samples by extraneous metals. All glassware, sample containers, and materials were subjected to a rigorous 10 day procedure of acid washing in metal-free nitric acid. When possible materials used were guaranteed sterile and metal-free. Respective acids were "low-metal" and all solutions were prepared using distilled deionized (18 Mega-ohm) water.

Results

Final estimated metal concentrations for the 15 eggs samples are reported in Table 1. The data are reported as ng metal/g wet weight of tissue and are background corrected using the procedural and reagent blanks. Metal concentrations of the standard reference materials are summarized as percent recovery compared

to certified values; the recovery values serve to indicate 1) efficiency of the digestion technique for the matrix of the test sample, and 2) precision and accuracy of quantification. Selenium determinations by ICP/MS are somewhat problematic due to the presence of interfering molecular ions formed in the argon carrier. Although the values reported here have been corrected for matrix effects, accuracy should be considered as $\pm 50\%$ at these concentrations. This is reflected in the high and somewhat variable recovery ($194.3 \pm 13.9\%$) of metal in the SRM oyster tissue sample compared to the expected certified values. The metal recovery rate for the remaining metals ranged from 85.5% to 111.6% for all except lead which was substantially elevated (152.2%).

The high zinc concentrations necessitated a sample dilution protocol ($200\times$ dilution) that to some degree compromised the overall sensitivity for the lower concentrations of other metals, particularly lead. The analyses of barium, mercury, and tin were consistently below detection limits for all samples; analytical detection limits were approximately 0.2, 0.4, and 0.1 ng/g respectively for these metals.

Discussion

In reviewing these data it should be kept in mind that the endangered species status of the California Least Tern precluded random sampling of eggs. Perforce, the samples available were restricted to eggs which failed to hatch and thus may not be representative of egg metal levels in the population as a whole. The endangered species status of the tern similarly precluded collection of adults for a comparison of egg and chick or adult tissue metals as done for other species (Gochfeld and Burger 1987). No archived egg samples from past years were available for a trend analysis as was recently done for Common Terns (*Sterna hirundo*) in New Jersey (Burger and Gochfeld 1988).

Some metals in animal tissues are of course naturally occurring and essential to metabolic processes. It is important to distinguish between these, some of which like zinc and copper are required in relatively high concentrations, and those which are contaminants or present in abnormally high and potentially toxic levels (Gochfeld and Burger 1987). This should be given greater attention in future analyses.

The highest levels of metal in Least Tern eggs were for zinc (12,741 ppb). Common Tern eggs in New Jersey were similarly high in zinc but appeared to be declining from mean levels of 43,200 ppb in 1971 to 22,000 ppb in 1981 and 18,894 ppb in 1982 (Gochfeld and Burger 1987; Burger and Gochfeld 1988). What constitutes a normally expected, as opposed to dangerously elevated, level still remains to be determined.

Metal levels for nickel, cadmium, and lead in Least Tern eggs (Table 1) were 23–49% of those reported for Common Tern eggs in 1982 and copper 68% higher; comparable data on chromium, selenium, barium, and tin were not presented (Burger and Gochfeld 1988). In this analysis barium, mercury, and tin concentrations were all found to be below detection limits. Mercury residue levels of 337–353 ppb have been reported in Common Tern eggs (Gochfeld and Burger 1987; Burger and Gochfeld 1988).

Selenium is a naturally occurring trace metal which is essential in small amounts but extremely toxic at elevated levels. The selenium levels recorded from addled eggs of Inland Least Terns (*Sterna antillarum athalassos*) and Piping Plovers

(*Charadrius melodus*) nesting along the Missouri River in 1988 were 1.06–2.31 mg/kg (ppm) wet weight (Anon. 1990). These were thought to be within or over the toxic levels associated with embryo deformity and mortality in other species and possibly the cause of hatching failures in these two species (Anon. 1990). The levels of selenium reported in the present study of California Least Terns were only about half those reported for these inland nesting birds but should still be viewed with some concern until more precise data are available. Further comparative analyses, particularly of eggs which failed to hatch even after prolonged incubation and also ones deserted due to natural causes as tidal flooding should be initiated. This would help determine if there is a causal relationship between selenium levels and hatching failures in California Least Terns.

Lead levels in California Least Tern eggs were particularly variable, ranging from 0 to 744 ppb (Table 1). Some of this variability may have resulted from the levels being near the limits of detection and the extra dilution necessitated by the high zinc levels. Accordingly, the lead levels reported here should be viewed with some caution. None the less, the mean level of 112 ppb was markedly higher than the 2.14 ppb (dry weight) recorded from California Least Tern feathers (Boardman and Collins, *in press*) but much lower than the 406–446 ppb recorded from Common Tern eggs (Gochfeld and Burger 1987; Burger and Gochfeld 1988). Automobile exhaust gas has been identified as a major source of lead in urban environments (Grue et al. 1986) where it could easily contribute to contaminant levels in run-off waters entering the coastal waters where the Least Terns forage (Waldron and Stofen 1974). These lead levels in California Least Terns are high enough to cause concern in other species (Pattee et al. 1990) and should be viewed with equal concern in this endangered species.

Additional analyses of California Least Tern eggs should be initiated to more precisely establish the metal levels currently present in the breeding population and if there is an increasing or decreasing trend in bioaccumulation. This is particularly true for selenium and lead, both of which may be causing a previously undocumented level of embryo death and reproductive failure. Recent population increases in the California Least Tern (Massey 1989) should not be allowed to overshadow the potential long-term detrimental impacts of elevated levels of toxic metals in this endangered species and its environment.

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Abundance, Diversity, and Seasonality of Cryptic Fishes and their Contribution to a Temperate Reef Fish Assemblage off Santa Catalina Island, California¹

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Abstract.—The populations of cryptic fishes in a rock-cobble shoreline habitat within Big Fisherman's Cove, Santa Catalina Island were assessed in relation to the local conspicuous fish populations. Sampling was conducted bimonthly over a one-year period from October 1984 to October 1985. Five random, 1 m² samples were taken from each of three depth strata (2.3–3.0 m, 4.2–5.1 m, and 6.4–7.6 m). *Lythrypnus dalli* was the most abundant fish (37% of total catch), followed by *Paraclinus integripinnis* (19%), *Gibbonsia elegans* (14%), *Alloclinus holderi* (12%), and *Lythrypnus zebra* (9%). The assemblage was markedly seasonal in terms of numerical and biomass densities with each being generally higher in warmer months. *L. dalli* were significantly more abundant in the deeper stratum while the density of *Paraclinus integripinnis* was greatest in shallower water.

The numerical density of cryptic fishes was, on average, four-times that of the conspicuous fishes as measured by diver transects (283/100 m² versus 71.5/100 m²). Inclusion of cryptic with conspicuous fishes increased the Shannon-Weiner Diversity (H') by an average of 41% (1.49 to 2.11) and increased the number of species by 50% (14 to 28 species). Cryptic fishes appear to make a substantial contribution to the abundance and diversity of fish assemblages inhabiting rock reef environments in southern California.

The accurate censusing of reef fish populations has long been a problem for fish ecologists. Reef fishes are particularly difficult to sample because the assemblages consist of two main groups with radically different lifestyles. The first group, referred to as conspicuous fishes are generally larger fish that swim in the water column, are not cryptically colored, may feed on the bottom, but seldom hide among rocks or algae. In contrast, cryptic fishes rest on or hide in the rocks and associated algae, primarily on the bottom and are well camouflaged. When disturbed, cryptic fish retreat into local hiding places. Quantitative assessment of these two, divergent types requires fundamentally different techniques.

The first quantitative studies of reef populations using SCUBA were conducted on coral reefs and consisted of SCUBA divers swimming transect lines and counting visible (conspicuous) fishes (c.f., Smith 1973). Although visual counts are reasonably accurate for estimating stocks of conspicuous fishes, they are grossly

¹ Contribution No. 66 to the Ocean Studies Institute.

inaccurate for estimating the abundances of cryptic fishes. Typically, cryptic fish populations have been collected by the use of ichthyocides which remains as the only method by which accurate counts may be obtained. Visual transects are well-established research tools for studying temperate reefs in southern California (Quast 1968a, b, c, d; Ebeling et al. 1980; Stephens and Zerba 1981; Larson and DeMartini 1984; Stephens et al. 1986; DeMartini et al. 1989; DeMartini and Roberts 1990). However, systematic assessments of cryptic fish assemblages are not well established. We believe the current investigation presents an effective methodology for the accurate quantification of cryptic fish assemblages.

In the first comprehensive study of temperate reef areas, Quast (1968a, b, c, d) presented a useful classification of the kelp bed ichthyofauna based on both SCU-BA transects and enclosed net poisoning. The various species were grouped into four types: Type I) fishes found in or closely associated with cover; Type II) the fishes that swim actively above the bottom during daylight, but remain oriented to kelp; Type III) fishes that utilize the open water spaces to the limit of landmark visibility; Type IV) transient pelagic fishes. Subsequent reports have used varied collection methods and have considered mostly conspicuous fishes (Feder et al. 1974; Ebeling et al. 1980; Stephens and Zerba 1981; Larson and DeMartini 1984). In one of the few recent reports dealing with cryptic fishes, Stephens et al. (1986) related the species composition and recruitment patterns of the fishes of a small reef in King Harbor, California to the abundance of available larvae. They found a correspondence between larval abundance and recruitment in *Lythrypnus dalli* and *Artedius creaseri*, but found little correspondence with all other species.

Prior to this report, only three studies (Quast 1968a; Stephens and Zerba 1981; and Stephens et al. 1986) included cryptic fishes in their assessments of reef fish assemblages. Quast (1968a) noted that the species frequency data would probably change significantly if the cryptic species had been recorded in his study. Still, the contribution made by cryptic fishes to the abundance, biomass and diversity of fishes in a rock reef/kelp forest habitat in southern California remained poorly understood. Allen (1985) pointed out that the potential impact of the addition of cryptic species on fish diversity is unclear. However, even a modest increase in the fish diversity due to the contribution of cryptic fishes could rank kelp bed and rock reef habitats higher in diversity than the offshore soft bottom habitat. If this is the case, kelp beds and rock reefs would be considered the most diverse fish habitats in the Southern California Bight.

The present study was undertaken specifically to determine: 1) numerical abundance, 2) species composition, 3) seasonality, 4) depth distributions, and 5) the diversity of the cryptic fishes inhabiting the rocky subtidal of Big Fisherman's Cove, Santa Catalina Island, California. This information on cryptic species allowed a comparison of the relative contributions of cryptic versus conspicuous fishes to the abundance and diversity of the fish community inhabiting Big Fisherman's Cove.

Methods

The study site is located along the southeastern side of Big Fisherman's Cove on Santa Catalina Island, California (Fig. 1; 33°27'N, 118°29'W). The substrate of the site was a relatively homogeneous mixture of cobble and bedrock. The study area was approximately 150 m wide and reached a depth of 9 m where it was bounded by a sand flat. This rocky area supported a kelp forest in the past,

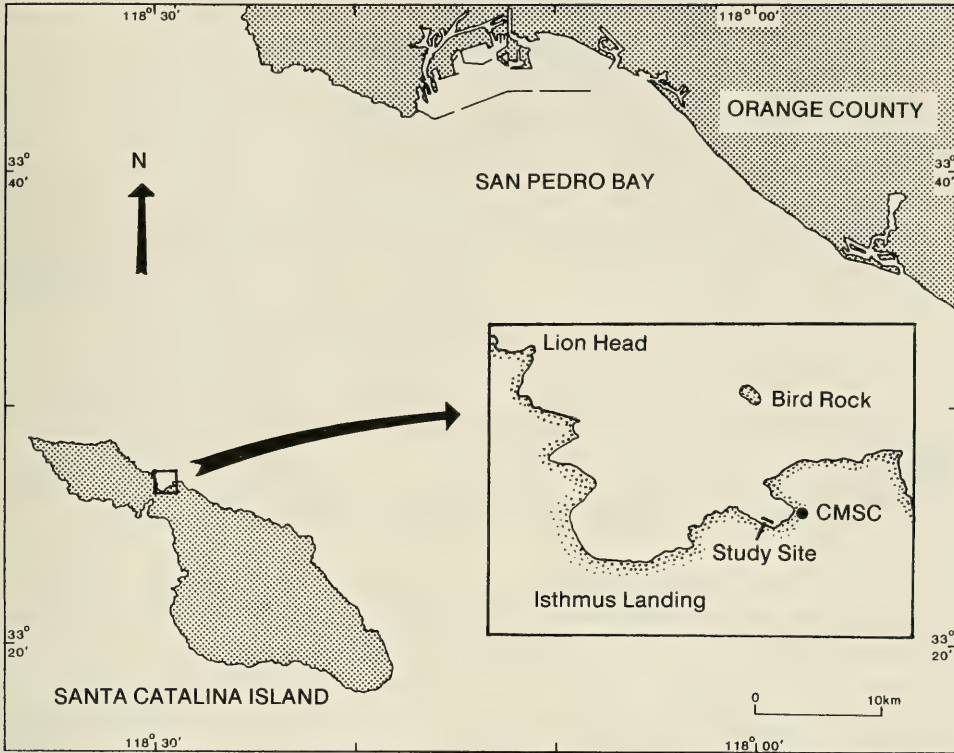


Fig. 1. Location of the study site within Big Fisherman's Cove, Santa Catalina Island, California (CMSC = Catalina Marine Science Center, University of Southern California).

although no kelp was present during the study. Abundant turf algae covered the rocks, including such species as *Dictyopteris undulata*, *Cystoseira osmundacea*, and *Colpomenia sinuosa*.

Seven collections were made using SCUBA at approximate two-month (bi-monthly) intervals: 5–8 October 21–25 November 1984, 8–11 February 1–4 April, 31 May–3 June, 2–5 August, and 4–7 October 1985. Fishes were collected using a specially designed enclosure net (Fig. 2). A square-meter base frame made of 2.5 cm PVC pipe was covered with a weighted canvas skirting extending down 25 cm from the frame. The canvas also extended up from the frame for 60 cm to the top of the net. The top included 60 cm of 3 mm mesh netting. The net was closed at the top by a drawstring which provided easy access to the interior of the enclosure. Divers lifted the collapsible net above the substrate at the depth stratum to be sampled, gave it a hard shove, allowed it to settle haphazardly on the bottom, and then anchored the edges with rocks. Crystalline rotenone saturated in 100 ml of acetone was injected by syringe into the area through the netting. The netting was tucked under the muslin, secured by velcro straps, and weighted down with rocks. The apparatus was left undisturbed for at least 10 minutes. During this time a second net was set in the same manner. After 10 minutes, the first net was opened and all fish were collected from the net by hand. When the search was completed, the net was set at a third location. The entire process was repeated until five samples were taken at each of three depth strata: 2.2 to 3.0 m (shallow), 4.2 to 5.1 (mid), and 6.4 to 7.6 m (deep). Five replicates represented

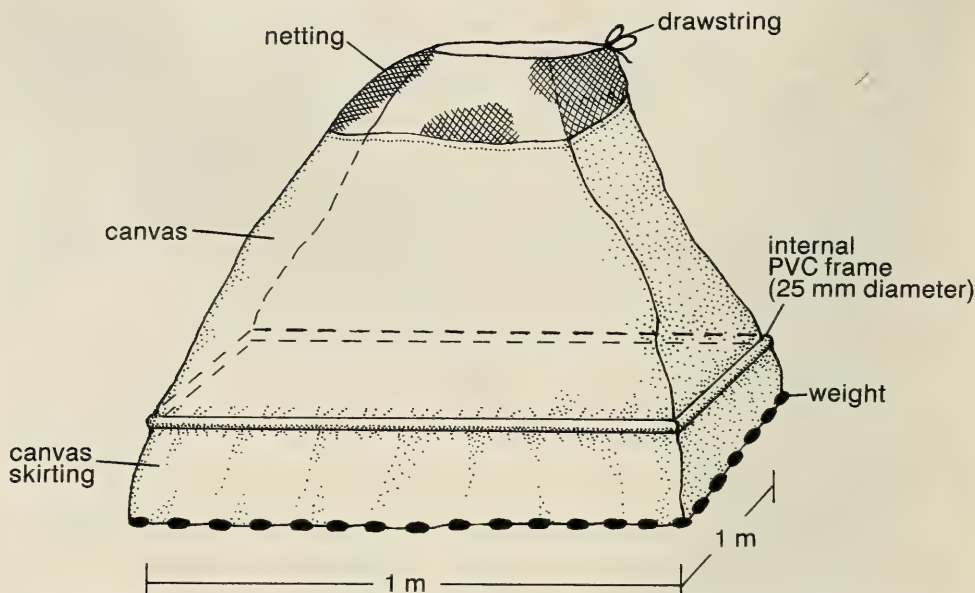


Fig. 2. Diagrammatic representation of net used to collect cryptic fishes. PVC frame delineates a 1 m^2 area of bottom.

the highest number which could be taken at each depth in the allotted time. In October 1984, the five replicate samples within each depth strata were combined inadvertently in the field before recording. Therefore, variance estimates among replicates are not available for this sampling date.

Conspicuous fishes in the area were also censused by visual diver transects two times, six months apart in April and October 1985. On each sampling date, two divers swam a 1 m high $\times$ 2 m wide $\times$ 75 m long transect together counting all conspicuous fishes within the 150 m^3 volume. Counts made by the two divers were averaged for each transect. This procedure was repeated twice at each of the three depths sampled by net collections.

The fish collected in the net were preserved in formalin for four days. Specimens were weighed to the nearest 0.1 gram and standard length was measured to the nearest 1 mm in the laboratory.

Among cryptic fish samples, we tested for the effects of depth and time (sampling date) on the number of species, the number of all individuals and the number of individuals of each of the five most abundant species using a two-way analysis of variance (ANOVA) with replication. Correlation coefficients (r) were calculated for water temperature versus the number of species, number of all individuals, the number of individuals of each of the five most abundant species, total biomass, and diversity (Shannon-Weiner, H').

Results

Cryptic Fishes

Species composition. — The assemblage of cryptic fishes consisted primarily (90%) of five species: *Lythrypnus dalli* (bluebanded goby), *Paraclinus integripinnis* (reef finspot), *Gibbonsia elegans* (spotted kelpfish), *Alloclinus holderi* (island kelpfish),

and *Lythrypnus zebra* (zebra goby) (Table 1). Numerically, *Lythrypnus dalli* was by far the most abundant resident species comprising 37% of total individuals, followed by *P. integripinnis* (19%), *G. elegans* (14%), *A. holderi* (12%), and *L. zebra* (9%). Two, less abundant, but resident fishes included *Bryx arctus* (snubnose pipefish) and *Artedius creaseri* (roughcheek sculpin). However, the species with individuals of the greatest average size dominated the catch in terms of biomass (Table 2). *Alloclinus holderi* comprised about 41% of the biomass followed by *Gibbonsia elegans* (27%) and *Paraclinus integripinnis* (15%). *Lythrypnus dalli* which ranked first in numerical abundance was only fifth in weight (4%) due to the small size of the average individual.

Two families were predominant: Gobiidae and Clinidae. Other families represented in the collection are Syngnathidae, Cottidae, Labridae, Serranidae, Blenniidae, Gobiessocidae, and Scorpaenidae.

Seasonality.—Variance among replicate samples within each depth were predictably high with Coefficients of Variation (CV) usually well over 1.0 which is not unusual for samples of fish assemblages. For this reason, variation is described as $\pm$ S.E. in the text, but is not illustrated in the figures for the sake of simplification.

The greatest numerical density (indiv./m²) of all species combined occurred in October of 1984, 6.8 (S.E. unknown) (Fig. 3). Henceforth, abundance decreased until April 1985, where it reached the lowest point of 2.4 ($\pm$ 1.5). The numbers steadily increased again until August 1985 (3.6 ± 3.6). This pattern of seasonal abundance was strongly influenced by changes in density of the numerically dominant species, *Lythrypnus dalli* (Fig. 4) which also corresponds well to the change in water temperature. The warmest months were October 1984 and August 1985, when the water reached 20.9°C. The water was coldest in February 1985, cooling to 13.7°C. A significant correlation existed between mean temperature and number of individuals ($r = 0.433$; $P < 0.05$).

The individual depth strata did not all closely follow the trend of the combined depth strata. The shallow stratum had the highest peaks of numerical density in October 1984 and June 1985, 6.0 (S.E. unknown) and 4.2 ($\pm$ 2.3), respectively, and the lowest point in November 1984 of 1.0 ($\pm$ 0.0). These did not correspond to the changes over time of the overall abundance. The middle depth followed the pattern of the overall abundance with highest abundances in October 1984 (6.6, S.E. unknown) and August 1985 (6.0 ± 5.2), and the lowest in February 1985 (1.4 ± 1.3). The deepest stratum had the greatest abundance in October 1984 (10.8), but the abundance steadily declined until August 1985 (1.8 ± 2.0), with a slight increase in October 1985.

The greatest biomass density (Wet Weight; gWWT/m²) of total fishes occurred in October 1984 and October 1985, 5.2 and 5.7 ($\pm$ 3.1), respectively (Fig. 3). The lowest biomass estimate was encountered in April 1985 (1.3 ± 1.3). Biomass generally decreased from October 1984 to April 1985, and then increased steadily.

The total number of species remained relatively constant among surveys ranging only between six and nine species (Fig. 3). The highest species total was in February 1985 (9 species) and the lowest in October 1985.

H' diversity was relatively consistent over the year (Fig. 3). The highest H' occurred in June 1985 (1.69) and August 1985 (1.72), whereas the lowest were encountered in November 1984 (1.40) and April 1985 (1.44).

Table 1. Number of individuals of species taken in seven, bimonthly surveys of cryptic fishes in Big Fisherman's Cove, Santa Catalina Island, October 1984 through October 1985.

Species	Month							Total	%
	Oct 84	Nov 84	Feb 85	Apr 85	Jun 85	Aug 85	Oct 85		
<i>Lythrypnus dalli</i>	60	23	19	14	4	20	6	146	37.34
<i>Paraclinus integripinnis</i>	23	14	4	4	8	9	11	73	18.67
<i>Gibbonsia elegans</i>	5	2	1	6	18	8	15	55	14.07
<i>Alloclinus holderi</i>	11	8	7	3	4	5	9	47	12.02
<i>Lythrypnus zebra</i>	6	2	5	6	8	5	4	36	9.21
<i>Bryx arcus</i>	7	1	1	1	3	1	1	15	3.84
<i>Artedius creaseri</i>			1	2		6		9	2.30
<i>Halichoeres semicinctus</i>	4		1					4	1.02
<i>Coryphopterus nicholsi</i>			1					1	.26
<i>Hypsoblennius jenkinsi</i>			1					1	.26
<i>Oxyjulis californicus</i>		1						1	.26
<i>Paralabrax clathratus</i>	1							1	.26
<i>Rimicola eigenmanni</i>					1			1	.26
<i>Scorpaena guttata</i>								1	.26
Total individuals	117	51	40	36	47	54	46	391	
Density (no./m ²)	7.80	3.40	2.67	2.40	3.13	3.60	3.07	3.72	
Number of species	8	7	9	7	8	7	6	14	

Table 2. Biomass (g) of species taken in seven, bimonthly surveys of cryptic fishes in Big Fisherman's Cove, Santa Catalina Island, October 1984 through October 1985.

Species	Month							Total	%
	Oct 84	Nov 84	Feb 85	Apr 85	Jun 85	Aug 85	Oct 85		
<i>Alloclinus holderi</i>	33.4	17.6	31.1	3.1	10.1	32.2	27.2	154.7	40.5
<i>Gibbonsia elegans</i>	8.4	12.3	9.0	11.9	11.1	7.1	44.8	104.5	27.4
<i>Paraclinus integririnnis</i>	10.5	5.7	2.0	4.1	13.3	10.9	10.2	56.7	14.8
<i>Paralabrax clathratus</i>	19.6							19.6	5.1
<i>Lythrypnus dalli</i>	4.0	2.1	3.1	1.8	.8	2.3	1.4	15.4	4.0
<i>Lythrypnus zebra</i>	.7	.4	1.0	2.8	2.6	1.8	1.6	10.9	2.9
<i>Artedius creaseri</i>			1.3	1.5		4.2		7.0	1.8
<i>Scorpaena guttata</i>					5.5			5.5	1.4
<i>Coryphopterus nicholsi</i>			3.9					3.9	1.0
<i>Hypsoblennius jenkinsi</i>			1.8					1.8	.5
<i>Bryx arctus</i>	.4	.1	.1	.1	.5	.1	.1	1.2	.3
<i>Halichoeres semicinctus</i>	.5							.5	.1
<i>Rimicola eigenmanni</i>					.3			.3	.1
<i>Oxyjulis californicus</i>		.1						.1	.1
Total	77.35	38.15	53.2	25.2	44.15	58.55	85.25	381.85	
Density (gWWT/m ²)	5.16	2.54	3.55	1.68	2.94	3.90	5.68	3.64	



Fig. 3. Numerical and biomass density, number of species and H' diversity of cryptic fishes for three depth strata combined by month over the period of October 1984 to October 1985.

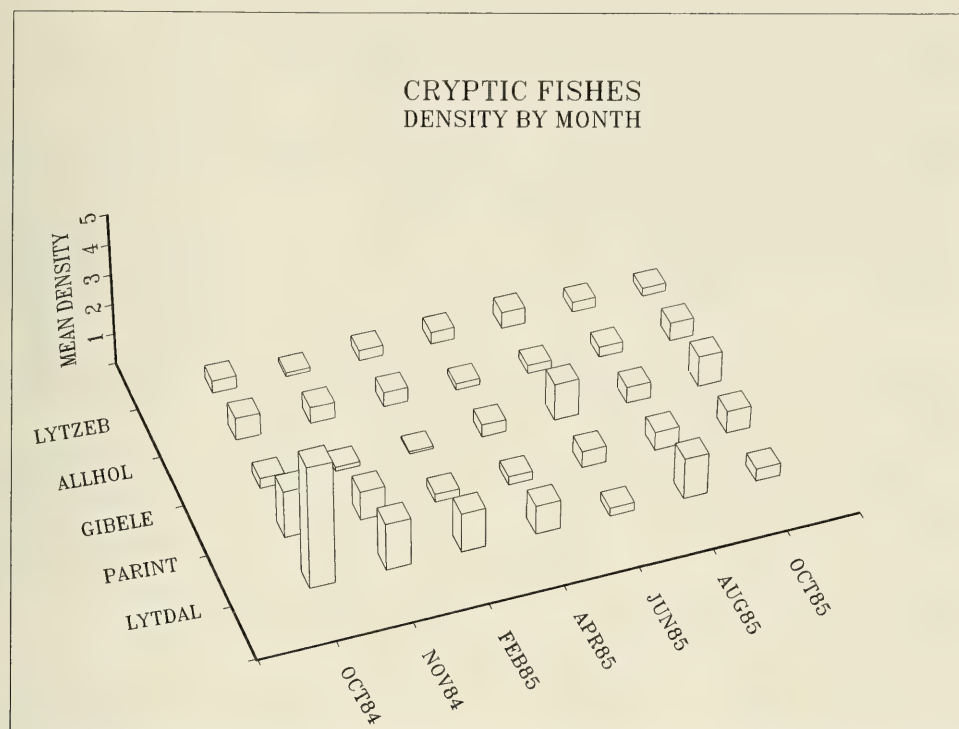


Fig. 4. Mean numerical density of the five most abundant species of cryptic fishes by month over the period of October 1984 to October 1985. (LYTDAL = *Lythrypnus dalli*; PARINT = *Paraclinus integripinnis*; GIBELE = *Gibbonsia elegans*; ALLHOL = *Alloclinus holderi*; LYTZEB = *Lythrypnus zebra*).

Lythrypnus dalli had its greatest abundance (and heaviest recruitment of juveniles, <15 mm SL) in October 1984 (4.0, S.E. unknown) and the lowest abundance in June 1985 (0.3 ± 0.5) (Fig. 4). Abundance declined from October 1984 until June 1985, and then increased in August 1985.

Mean numerical density of *Paraclinus integripinnis* was greatest in October 1984 (1.5, S.E. unknown) and lowest in February and April 1985 (0.3 ± 0.8 , and 0.3 ± 0.5) (Fig. 4). The correlation coefficient of temperature versus density of *P. integripinnis* individuals ($r = 0.714$) approached ($0.10 > P > 0.05$) statistical significance.

Gibbonsia elegans was most abundant in June 1985 (1.2 ± 1.0), with low abundances in November 1984 and February 1985 (0.1 ± 0.4 and 0.1 ± 0.3) (Fig. 4). The numerical density of *G. elegans* was low at the beginning of the study, but by the end was greater than *P. integripinnis*, the second most abundant species overall. This increase in density of *G. elegans* over the course of the study was statistically significant (Two-way ANOVA, time effect, $F = 4.86$, $df = 4,60$, $P < 0.001$).

Alloclinus holderi and *Lythrypnus zebra* had comparatively low abundance overall but exhibited opposite abundance patterns (Fig. 4). *A. holderi* was abundant in October 1984 (0.7). Abundance thereafter decreased to a low of 0.2 ± 0.2 in

April 1985. Numbers then increased steadily from June 1985 to October 1985 (0.6 ± 0.4). Abundance of *L. zebra* began low in October (0.4) and November 1984 (0.1 ± 0.1) and increased to a high of 0.5 ± 0.2 in June 1985. *L. zebra* abundance then decreased to 0.3 ± 0.2 in both August and October 1985.

Depth distributions.—The mean numerical density of individuals of all species was virtually the same for all three depth strata (3.2 ± 2.9 , 2.9 ± 1.8 , and 3.1 ± 3.8) in the shallow, middle, and deep strata, respectively. However, the five most abundant species differed from one another in their depth distributions (Fig. 5). Density of *Lythrypnus dalli* increased as depth increased (Two-way ANOVA, depth effect, $F = 4.09$, $df = 2,60$, $P < 0.05$). *Paraclinus integripinnis* exhibited an opposite though not statistically significant trend, with more individuals at shallower depths. Density of *Gibbonsia elegans* generally decreased with increased depth. *Alloclinus holderi* and *Lythrypnus zebra* changed little from one stratum to another, but had slightly more individuals in the middle stratum.

The sampling procedure used in this study was effective at capturing small, newly recruited individuals among the five most abundant species. Newly recruited individuals (5–9 mm and 10–14 mm SL size classes) of the most abundant species (*Lythrypnus dalli*), were encountered in October 1984, November 1984, February 1985 and August 1985. The smallest size class only occurred in October 1984. The second most abundant species, *Paraclinus integripinnis* appears to have recruited in both October 1984 and October 1985 when individuals from 10–14 mm SL size range occurred in the collections. The smallest individuals (15–19 and 20–24 mm SL class) of *Gibbonsia elegans* were collected in April, June, August, and October 1985. Prior to April 1985, all sizes of *G. elegans* were rare in our samples. Only one newly recruited individual (10–14 mm SL class) of *Alloclinus holderi* was captured during the study and that was in November 1984. Small *Lythrypnus zebra* were only collected in October 1984. These individuals were in the 10–14 mm SL size class and probably represented newly recruited juveniles. Only a few individuals of *L. zebra* were collected during 1985, and new recruits were not among them.

Conspicuous Fishes

Almost 90% of all fishes counted on visual transects during April and October 1985 belonged to four species: *Chromis punctipinnis* (blacksmith—36%), *Hali-choeres semicinctus* (rock wrasse—32%), *Paralabrax clathratus* (kelp bass—15%), and *Hypspops rubicundus* (garibaldi—6%) (Table 3). In April 1985, *H. semicinctus* (36%) ranked first followed by *C. punctipinnis* (32%), *P. clathratus* (18%), and *H. rubicundus* (4.1%), while in October 1985, *C. punctipinnis* (40%) ranked first with *H. semicinctus* (28%) second. High numbers of *C. punctipinnis* were obtained because of the large schools of juveniles swimming across the transect line while the census was being recorded. While the ranking of all other species varied, the list of species remained relatively consistent though the surveys were made six months apart, one in April in cooler water (14.3°C) and one in October in warmer water (19.9°C). Cryptic species were occasionally observed, but they were seen very infrequently. *Paraclinus integripinnis*, *Lythrypnus zebra*, and *Gibbonsia elegans* were never seen on the visual transects.

Shannon-Weiner diversity (H') was calculated including all three depth strata

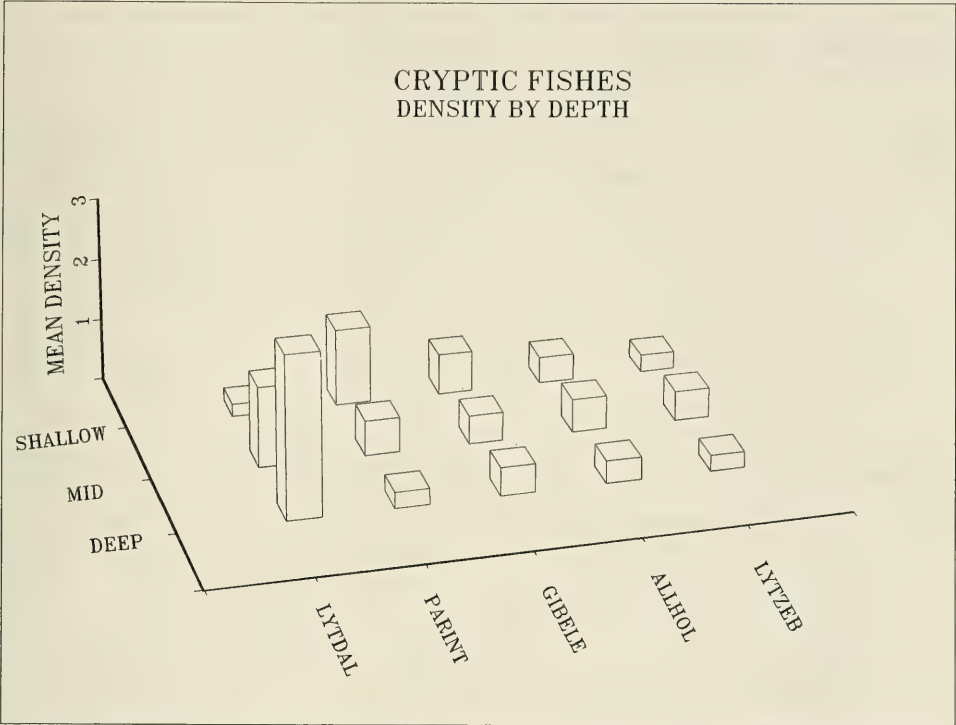


Fig. 5. Mean numerical density of the five most abundant species of cryptic fishes at each of three depth strata over the period of October 1984 to October 1985. (LYTDAL = *Lythrypnus dalli*; PARINT = *Paraclinus integripinnis*; GIBELE = *Gibbonsia elegans*; ALLHOL = *Alloclinus holderi*; LYTZEB = *Lythrypnus zebra*).

for the conspicuous fishes and for the conspicuous and cryptic fishes combined (Table 4). Diversity for the April and October 1985 surveys for conspicuous fishes was 1.37 and 1.61, respectively. Combining the cryptic and conspicuous fish counts increased the H' diversity by an average of 40%. In April 1985, the total H' diversity for cryptic and conspicuous fishes combined was 2.18, an increase of 59% over the H' measured for conspicuous fishes alone. In October 1985, the diversity of cryptic and conspicuous fishes together was 2.05. H' diversity was increased 24% by including the cryptic fishes.

The numerical density (indiv./100 m²) of cryptic fishes contributed greatly to the overall density of cryptic and conspicuous fishes combined during the months of April and October 1985 (Table 4). In April 1985 the density of cryptic fishes combined across all depths was 253 compared to 76 for the conspicuous fishes. Similarly, the total density of cryptic fishes in October 1985 was 313 compared to 67 for conspicuous fishes.

Fourteen species of cryptic fishes were collected during the study (Table 3). Likewise, fourteen species of conspicuous fishes were seen in visual transects in April and October 1985. The two sampling methods combined totaled 22 species (6 species were sampled by both methods). Therefore, the inclusion of cryptic fishes increased the total number of species by 57% from 14 to 22 species.

Table 3. Relative abundances of fish species in cryptic (CRYPTIC) versus conspicuous (CONSPIC) surveys in April and October, 1985.

Species	Percent abundance	
	CRYPTIC	CONSPIC
<i>Lythrypnus dalli</i>	36.2	1.8
<i>Paraclinus integripinnis</i>	18.8	
<i>Gibbonsia elegans</i>	13.9	
<i>Alloclinus holderi</i>	11.8	.2
<i>Lythrypnus zebra</i>	9.3	
<i>Syngnathus arctus</i>	3.9	
<i>Artedius creaseri</i>	2.1	
<i>Halichoeres semicinctus</i>	1	32.05
<i>Paralabrax clathratus</i>	.3	14.75
<i>Hypsoblennius jenkinsi</i>	.3	
<i>Rimicola eigenmanni</i>	.3	
<i>Scorpaena guttata</i>	.3	
<i>Coryphopterus nicholsi</i>	.3	.05
<i>Oxyjulis californica</i>	.3	2.2
<i>Chromis punctipinnis</i>		35.9
<i>Hypsypops rubicundus</i>		5.85
<i>Semicossyphus pulcher</i>		1.3
<i>Girella nigricans</i>		.6
<i>Embiotoca jacksoni</i>		.3
Grouper (unident.)		.05
<i>Brachyistius frenatus</i>		1.9
<i>Medialuna californiensis</i>		.85
Number of species	14	14
Total both = 22 spp.		

Discussion

Stephens and Zerba (1981) and Stephens et al. (1984) included benthic quinaldine samples attempting to assess the abundance and diversity of cryptic fishes. Twelve species of cryptic fishes were collected in 60 samples at King Harbor which was comparable to the nine species collected in 20 samples at Palos Verdes (Stephens et al. 1984). Stephens et al. (1986) recorded 23 species of fish, most of which were cryptic, recruiting to a subtidal reef (Cable Reef) in King Harbor over a 16-month period (July 1984–November 1985). *Lythrypnus dalli*, *Artedius creaseri*, *Hypsoblennius jenkinsi*, and *Neoclinus stephensae* dominated their collections numerically. Other cryptic species collected at Cable Reef included *Gibbonsia elegans*, *Paraclinus integripinnis*, *Scorpaenichthys marmoratus*, *Gobiesox rhesodon*, and *Scorpaena guttata*. Species composition within the assemblages of cryptic fishes in King Harbor and Catalina Island were similar although the rankings of abundance among the most common species varied.

A significant, positive correlation was found between temperature and the number of total fishes ($r = 0.43$; $P < 0.05$, $df = 20$). The abundance of individuals seemed to increase as water temperature increased, and decrease as the water temperature decreased. However, only one of the five most common species, exhibited a high, though not significant correlation between temperature and

Table 4. Comparison of density, abundance, and H' diversity of cryptic (CRYPTIC) and conspicuous (CONSPIC) fishes plus both combined for the surveys conducted in April and October, 1985.

Survey	Density No./100 sq. m	Abundance % Total	Diversity H'
April, 1985			
CRYPTIC	253.3	77.3	1.44
CONSPIC	76.2	22.7	1.37
COMBINED	331	100	2.18
October, 1985			
CRYPTIC	313.3	82.8	1.58
CONSPIC	67.3	17.2	1.61
COMBINED	383	100	2.05

abundance: *Paraclinus integripinnis* ($r = 0.32$; $0.10 > P > 0.05$). The variable abundance of individuals within species over time demonstrated a marked seasonality in the cryptic fish assemblage during the study period. However, these patterns are not explained by changes in temperature alone.

Even though monthly H' diversity remained relatively stable over the study period, H' and water temperature were significantly correlated ($r = 0.459$; $P < 0.05$) despite a February 1985 anomaly. This was the coldest sampling date of the study, but the H' value was as high as some of the warmer months. Stephens et al. (1986) found higher numbers in the species favoring warmer water conditions at the end of the El Nino event in 1985.

Algal species composition remained the same throughout the present study. Qualitatively, the amount of algae increased during warmer months. During this time algae covered a higher percentage of the rocks and grew taller, enhancing three-dimensional structure which provided more habitat for cryptic fishes. Densities of both young-of-the-year and juvenile *Alloclinus holderi* and *Gibbonsia* species were greater in plots cleared of giant kelp, *Macrocystis pyrifera*, in which percent cover of benthic algae sampled was twice that of plots in which giant kelp was left intact (Carr 1989).

Moreover, seasonal variation in larval recruitment undoubtedly exerted a major influence on the seasonal patterns as evidenced by the high number of recruits in the collections.

Few differences were apparent between the three different depth strata sampled. Of the five most abundant species, only the two numerically dominant species seemed to show any preference for a particular depth stratum. *Lythrypnus dalli* were significantly more abundant in the deeper strata. *Paraclinus integripinnis*, though not showing a statistically significant difference among depths, tended to prefer shallower water. The possibility exists that some form of interaction exists between these two abundant species leading to the disparity of their distributions.

The inclusion of cryptic fishes in the estimates of numerical density would most likely have greatly increased the counts obtained by Ebeling et al. (1980) and Larson and DeMartini (1984). At Catalina, the conspicuous fish numerical density for April 1985 was 0.763, while the cryptic fish density was 2.533, making a total of 3.296 and increasing the density by 77%. October 1985 had similar numbers;

the density of conspicuous fishes was 0.673, the density of cryptic fishes was 3.133, and the total density was 3.807, an increase of 82%. If proportional numbers of cryptic species are postulated for the numbers of conspicuous species obtained by Ebeling et al. (1980), the overall numerical densities are increased considerably. Their Santa Barbara mainland location would have a cryptic fish population density of 0.551, and a total density of 0.690. The Santa Cruz Island location would have a cryptic fish density of 0.546. This proportion must be applied with greater caution to the cobble bottom reefs studied by Larson and DeMartini (1984) since the number of available shelters at these sites are probably much lower. If the proportions are applied these San Onofre sites would have a cryptic population density of 0.450 and 0.699, and total densities of combined cryptic and conspicuous fishes would be 0.564 and 0.876. These numbers represent an 80% difference in total densities.

The contribution of cryptic fishes to the biomass density of the area was estimated to be only about 10% of that of the conspicuous fishes. However, it is possible that the small size, fast growth, and short lives of these cryptic fishes translate into relatively high productivity due to the quick turn-over of biomass.

Shannon-Weiner diversity (H') is another aspect of the community that was enhanced by the presence of the cryptic fish population. H' of the conspicuous fishes for April and October 1985, were raised 60% and 27%, respectively and the average increase in H' at Catalina was 44%. If this same average increase is postulated for Ebeling et al. (1980) and Larson and DeMartini (1984), H' diversity would also have been enhanced significantly. H' for these studies was calculated by Allen (1985). Ebeling et al. (1980) and an H' of 2.23 for the mainland and 2.30 for the island locations, and may have been increased to 3.21 and 3.31, respectively with the incorporation of the cryptic fishes. Larson and DeMartini (1984) had H' of 1.67 and 2.27 for their two sites. Incorporation of cryptic fishes may have increased to as much as 2.40 and 3.27. The reduced heterogeneity of these cobble-bottom kelp beds makes it unlikely that true values would be quite as high as these estimates.

Consideration of cryptic fishes in density and diversity estimates of fish assemblages in rock reef and kelp bed habitats may increase the overall fish densities by as much as 82% and H' diversities by as much as 60%. If these approximations are valid then rock reef and kelp bed habitats could easily be the most diverse of all southern California fish habitats (Allen 1985).

In conclusion, the cryptic fishes from Big Fisherman's Cove were found to be small, very abundant, and diverse. Their contribution to the abundance and, especially to the diversity of fishes inhabiting this rock reef environment was substantial. Obviously, we believe that cryptic fishes should not be ignored in future assessments of reef fish assemblages in southern California.

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Colorado River Fishes of Lake Cahuilla, Salton Basin, Southern California: A Cautionary Tale for Zooarchaeologists

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Abstract.—Since the late Pleistocene the Colorado River has periodically filled the Salton Basin of southern California to form a huge lake, Lake Cahuilla. Fish remains recovered from archaeological sites occupied about 500 years B.P. along the shores of the last highstand of this lake have been identified as razorback sucker, *Xyrauchen texanus*, Colorado squawfish, *Ptychocheilus lucius*, striped mullet, *Mugil cephalus*, machete, *Elops affinis*, and bonytail, *Gila elegans*. For a number of reasons some of these identifications are considered tentative; the zoogeographic basis is doubtful (*G. robusta*, *G. cypha*, and the sucker *Catostomus latipinnis* may also have been present), taxonomic imprecision makes early range determinations unreliable, the remains are fragmentary, and individual variation and potential hybridization make definitive determinations challenging. Zooarchaeologists need to be aware of and address these types of difficulties when they are encountered.

Since at least the late Pleistocene the Salton Basin of southern California has periodically filled and desiccated as the Colorado River altered its course en route to the Gulf of California (Hubbs and Miller 1948; Wilke 1978; Waters 1983; Sutton and Wilke 1988). When the basin filled, a productive freshwater lake, Lake Cahuilla, was formed. It reached a maximum size of 185 km long, 56 km wide, and over 91 m deep. The most recent cycle of filling followed by desiccation took place approximately A.D. 900 to A.D. 1500 (Sutton and Wilke 1988). The basin partially filled during 1905–1906 due to an accidental course change of the Colorado River and remained fresh until about 1930. Today the Salton Sea is the saline remnant of this overflow and is maintained by agricultural run-off. Its fish fauna consists of introduced marine sport fishes (Walker et al. 1961; Moyle 1976).

Fish remains recovered during the excavation of archaeological sites on the former shores of Lake Cahuilla provide a rare opportunity to identify the fishes that inhabited this ancient lake. These remains are important not only for their archaeological value, but also because they provide clues to the ecology of a fish fauna that is largely extinct or endangered (Williams et al. 1989).

Fish remains recovered from archaeological sites have provided information on the zoogeography and associations of native freshwater fishes (Miller 1955; Gehlbach and Miller 1961; Minckley and Alger 1968; Schulz and Simons 1973; Casteel 1976; Schulz 1979; Gobalet 1990). It is the objective of this study to record the ichthyofauna of Lake Cahuilla based on archaeological studies and to discuss difficulties inherent in establishing definitive identifications.

The frequent lack of rigor in the discipline of zooarchaeology is troubling. Data are presented in the poorly circulated gray literature that is not subjected to peer review. Little more than species lists often appear in cultural resource management reports and they generally do not consider the biology of the species identified. This does not promote confidence in the findings. Fish remains recovered from the former shores of Lake Cahuilla provide an opportunity to discuss problems that may arise from limited familiarity with the species present.

Zoogeographic Context

Identification of faunal remains often is initially based on expectations resulting from knowledge of the present distribution of fishes. Miller (1961) and Minckley et al. (1986) have comprehensively reviewed the native fish faunas of the Colorado River drainage. Early records of the fishes are few because early surveys were not thorough and major habitat alterations, species introductions and extirpations had already occurred. As a result, species lumping may have occurred which would have excluded certain recognized species.

Miller (1961) reported the following species from the lower Colorado River near Yuma, Arizona: bonytail (*Gila elegans*), razorback sucker (*Xyrauchen taxanus*), Colorado squawfish (*Ptychocheilus lucius*), striped mullet (*Mugil cephalus*), machete (*Elops affinis*), woundfish (*Plagopterus argentissimus*), desert pupfish (*Cyprinodon macularius*), and Gila topminnow (*Poeciliopsis occidentalis*). Evermann (1916), Hubbs and Miller (1948) and Miller (1961) each reported only a single *Gila*, the bonytail, from either the Salton Basin or the lower Colorado River. Other records suggest that more than one chub occupied the lower Colorado and potentially Lake Cahuilla. Minckley (1973, 1983) reported *Gila robusta*, roundtail chub, from the lower Colorado River and Sigler and Miller (1963) report observations of its spawning in Lake Mohave, Nevada. Miller (1955) extended the range of *Gila cypha*, at least prehistorically, into the lower Colorado River and D. G. Buth (pers. comm. 1990) identified one captured in the 1950's from the lower Colorado River. Since *G. cypha* was not recognized as a separate species from *G. elegans* until 1946 (Miller 1946), the prior records of distribution and abundance of these species are tenuous (Valdez and Clemmer 1982).

Potentially there were three large chubs in the lower Colorado River that may have inhabited Lake Cahuilla: *G. cypha*, *G. elegans*, and *G. robusta*. Flannelmouth sucker, *Catostomus latipinnis*, would also be expected from the lower Colorado River (Miller 1961; Minckley 1973).

Methods

Fish remains have been recovered during excavations of archaeological sites in the La Quinta region of Riverside County, California (Fig. 1). Ten archaeological sites (CA-RIV-1182, -1769, -2196, -2936, -3143, -3144, -3681, -3682, -3683, and -3793) have been excavated by the Archaeological Research Unit of the University of California, Riverside and the findings have been recorded in a series of unpublished reports (UCRARU #970, #977, #1014, #1023, #1027, #1044). These sites bordered Lake Cahuilla and were occupied during the later stages of its last stand, A.D. 1300–1500. Fish remains recovered during these excavations have been identified and compared with findings of other investigators.

Identifications were determined by comparisons with skeletons listed in the



Fig. 1. Location of archaeological sites relative to highstand of Lake Cahuilla, A.D. 900-1500.

materials examined section. Plates in Miller (1955), Gehlbach and Miller (1961) and Miller and Smith (1984) were useful as were photographs of the spinal columns of razorback sucker, bonytail (CAS, Accession No. 1962-II:23) and Colorado squawfish (CAS 26210) (taken under the direction of W. I. Follett). Pharyngeals, teeth, basioccipitals, asterisci, and interneurals were particularly closely examined. Fish names follow Robins et al. (1980).

Results and Discussion

All five of the fishes identified from these ten sites (Table 1), razorback sucker, bonytail, Colorado squawfish, machete (*Elops affinis*) and striped mullet (*Mugil cephalus*) have previously been identified at archaeological sites in the Salton Basin. Though the identifications of bonytail and razorback sucker at these ten sites were made with confidence, they are subject to the qualifications that follow.

Table 1. Number of fish remains recovered from archaeological sites in the Salton Basin of southern California.

	RIV- 1182	RIV- 1769	RIV- 1179 ^a	RIV- 2196	RIV- 2827 ^a	RIV- 2936	RIV- 3143	RIV- 3144	RIV- 3681	RIV- 3682	RIV- 3683	RIV- 3793	JM-1 ^b	Anza- Borrego ^c	Total
Bonytail	142	469	1043	38	82	2	6	7	—	472	3	1	295	106	2666
Razorback Sucker	239	431	276	52	60	3	3	9	1	366	3	78	48	12	1581
Colorado Squawfish	—	17	78	—	—	—	—	—	—	11	—	4	—	—	110
Striped Mullet	5	—	—	—	1	1	—	—	—	35	1	1	18	—	62
Machete	—	—	—	—	—	—	—	—	—	1	—	—	1	—	2

^a Follett 1988.
^b Salls unpublished data.
^c Yohe et al. 1986.

Follett (1988) found all of these fishes except the machete at RIV-1179 and only bonytail and razorback sucker at RIV-2827. In the La Quinta dune area (JM-1) Salls (unpub. data) reported all but the Colorado squawfish. Yohe et al. (1986) found remains of bonytail and razorback suckers at Indian Hill Rockshelter, Anza-Borrego Desert State Park. L. T. Findley (pers. comm. 1991) identified these species at sites in the southern portion of the Salton Basin. At the Magma sites in Imperial County, Follett (1979) reported the fish remains by percent of total weight of remains: .62% bonytail, 44.64% razorback sucker, 20.02% probable razorback sucker, .74% striped mullet, and 33.98% unidentified fragments. Follett, Salls and Yohe et al. have not described the basis for their faunal identifications, making verification difficult.

Gila sp.

There are numerous problems in the systematics of minnows of the genus *Gila* (Uyeno 1960; Hopkirk 1973; Hubbs et al. 1974; Moyle 1976; Bills 1978). Holden and Stalnaker (1970), Minckley (1973), Smith et al. (1979), Kaeding et al. (1986, 1990), Douglas et al. (1989, 1991), and Buth et al. (1990) have addressed taxonomic problems of the *Gila robusta* complex of the Colorado River drainage. Because the systematics of these forms is controversial even when whole animals are considered and because fragmentary elements are the basis for these identifications, caution is necessary in identifying these remains as bonytail. A nearly complete pharyngeal might confidently be identified as bonytail, but a fragmentary pharyngeal is problematic since members of the *Gila robusta* complex are so anatomically similar (Fig. 2).

Holden and Stalnaker (1970) and Smith et al. (1979) recognized three separate *Gila* species despite the existence of intermediate forms between *G. robusta* and *G. elegans* and between *G. cypha* and *G. elegans*. Large numbers of these (hybrids?) were found in Lake Powell possibly resulting from habitat changes following the construction of Glen Canyon Dam (Holden and Stalnaker 1970). Kaeding et al. (1986) found considerable intergradation between *G. cypha* and *G. robusta* in western Colorado and Kaeding et al. (1990) suggested that offspring of this cross would be viable.

Since today intergrades exist between all three species of *Gila* potentially present in Lake Cahuilla, it is possible that such intergrades existed there. The rapid initial flooding of the Salton Basin to form Lake Cahuilla could have been a catastrophic event creating a disturbed habitat leading to hybridization. Weisel (1955) illustrated how single bones of an intergeneric cyprinid hybrid have a form intermediate between those of the parents. Single elements from such a hybrid would be difficult to impossible to identify to species, particularly if fragmentary, the most common condition.

A *Gila sp.* pharyngeal found at RIV-3682 shows evidence of an unusual third tooth in its inner row (Fig. 2C). A third tooth is found only in the inner row of three of thirty-two roundtail chub pharyngeals (AMNH 47091, AMNH 47096) suggesting roundtail chub were present. There is considerable variation in pharyngeal tooth number and position in members of the *Gila robusta* complex. One of twelve pharyngeals of bonytail has two teeth in its highly unusual intermediate row and one of four pharyngeals of humpback chub lacks an inner row. Roundtail chub pharyngeals also occasionally have an unusual single tooth in a middle row

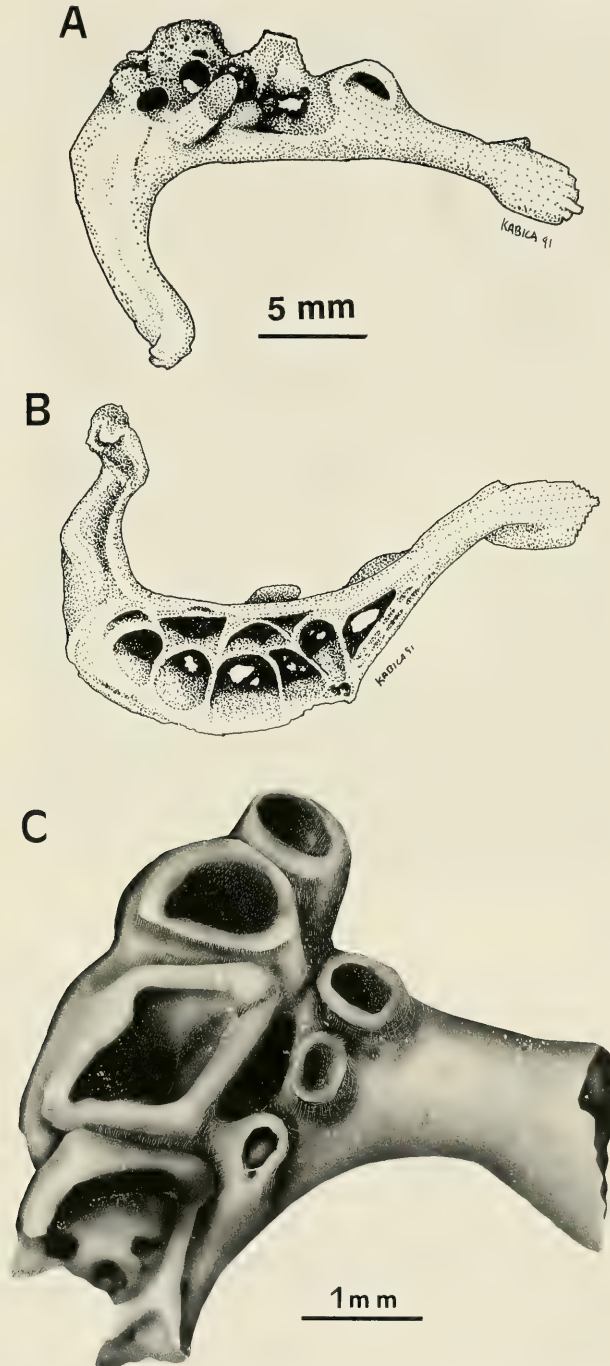


Fig. 2. *Gila elegans* from CA-RIV-1182. Right pharyngeal missing most teeth: A, dorsal view; B, ventral view. C, *Gila* sp. from CA-RIV-3682. Left pharyngeal fragment with unusual third tooth in the inner row.

(UMMZ 179580, CAS 25851). The shape of the more complete recovered pharyngeals however are the most like bonytail. The tui chub, *Gila bicolor*, of the *Siphateles*-type within the genus, however, have great uniformity of dentition with a single pharyngeal of 157 examined possessing a supernumerary tooth in its single row.

The 25 *Gila* sp. basioccipitals examined from these archaeological sites however show extraordinary homogeneity in the shape and degree of concavity of their masticatory plates. Sixty-four basioccipitals of comparative tui chubs, on the other hand, show considerable variation in the shape, thickness and degree of concavity of their plates. The homogeneity of the Lake Cahuilla specimens may in fact result from the lack of genetic diversity of a few founders. Even greater variation in tooth count in the recovered pharyngeals would be expected based on the variation among the comparative specimens. Considering the potential for hybridization, the range of individual variation, and with questionable zoogeography, identification to species in the genus *Gila* should be cautiously made.

Bonytail and humpback chub have a characteristic humpbacked form and narrow caudal peduncular morphology that are convergent with those of the razorback sucker. Though these specializations are associated with survival in strong currents resulting from periodic flooding of the Colorado River (Minckley and Mefee 1987), bonytail, like the razorback sucker, breed in (Sigler and Miller 1963) and spend much time in pools and eddies (Moyle 1976). The fingerling bonytail found in coprolites by Wilke (1978) suggest spawning and recruitment in Lake Cahuilla, though Wilke does not indicate the basis for this identification. Much like the congeneric tui chub of Eagle Lake, California (Kimsey 1954), and Lake Tahoe, and Pyramid Lake, Nevada, the omnivorous bonytail (or other *Gila* sp.) probably thrived in Lake Cahuilla. A filter feeding lacustrine form comparable to *G. bicolor pectinifer* bearing numerous gill rakers (see Kimsey 1954; Hubbs 1961; Cooper 1985) might even have become abundant.

Razorback Sucker

Razorback suckers apparently were quite abundant in Lake Cahuilla (Table 1). Diagnostic interneurals helped confirm razorback sucker identification but the considerable variation in morphology of its asterisci (Fig. 3) leads one to caution in identification.

Though Dill (1944) reported that the razorback sucker is a bottom feeder, Minckley (1973), Marsh (1987), and Papoulias and Minckley (1990) have confirmed that it is primarily a planktivore. Its fimbriate gill rakers (Miller and Smith 1981) suggest that it is a "pump filter-feeder," a feeding method by which the broad gill rakers "guide" particles to the pharyngeal jaws (Sanderson et al. 1991). It is probably the riverine equivalent of the lacustrine suckers of the genus *Chasmistes* (tribe Catotostomine; Hubbs and Miller 1953). Razorback suckers probably thrived in a plankton rich Lake Cahuilla.

Since razorback suckers breed in the shallow waters of reservoirs (Sigler and Miller 1963), it is likely that they spawned along the shore of Lake Cahuilla and thus avoided migratory runs, though Hubbs (1960) reported evidence of successful prehistoric spawning in Fish Creek, a tributary of Lake Cahuilla. The tendency of razorback suckers to feed inshore in small schools (Moyle 1976) and their spawning in shallow water made them the easy prey of Native American fishermen

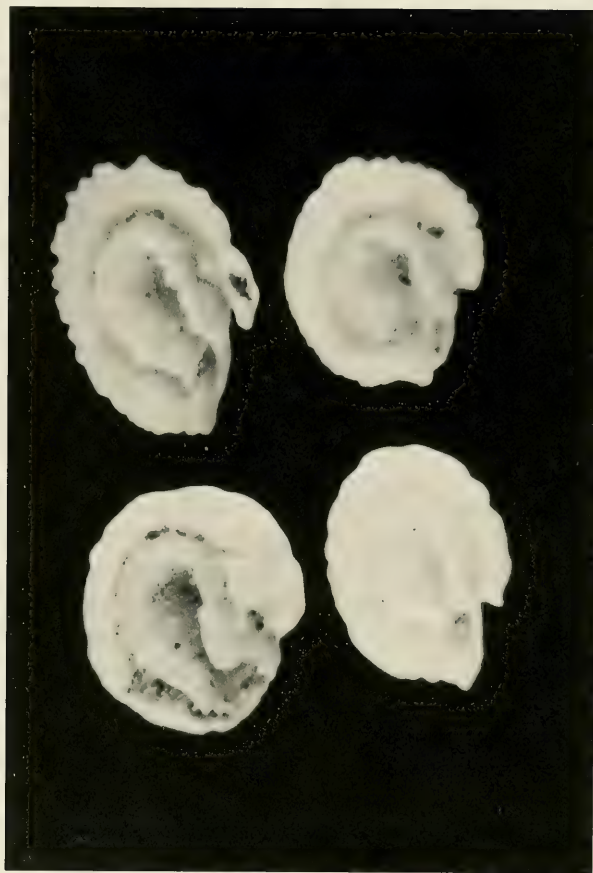


Fig. 3. *Xyrauchen texanus*: Individual variation in asterisci from archaeological sites; A, CA-RIV-3682; B, CA-RIV-3793; C, CA-RIV-2196; D, CA-RIV-3793.

along the lower Colorado River (Castetter and Bell 1951; Miller 1955; La Rivers 1962). Razorback suckers which reached a meter and 6 kg (Minckley 1973) were easily snared by pulling grab hooks through a school (Sigler and Miller 1963). "Old timers" in Phoenix considered them an excellent food (Minckley 1973). The cui-ui, *Chasmistes cujus*, another planktivorous sucker, was very popular with the Northern Paiute of Pyramid Lake, Nevada (Follett 1982). Despite attaining a greater size in the more sluggish parts of the Colorado River than in its headwaters (La Rivers 1962), razorback suckers have suffered greatly as a result of the reservoir system installed along the Colorado River. Though its larvae have been found in Lake Havasu on the Colorado River for the first time since the 1950's (Marsh and Papoulias 1989), the lack of planktonic food during the critical post hatching period between 19 and 28 days may explain the general lack of recruitment throughout its range (Papoulias and Minckley 1990). Predation by exotic fishes also limits its recruitment (Minckley 1983). Lake Cahuilla probably had the warmer temperatures reported by Tyus and Karp (1990) preferred by razorback suckers, as well as abundant plankton, and no exotic predators.

Colorado Squawfish

The Colorado squawfish (identified here by vertebrae, a basioccipital and a pharyngeal tooth) is the largest North American minnow and one time reached almost two meters and 45 kg (Holden and Wick 1982). It is the chief native piscivore of the Colorado River (Minckley 1973). It is now threatened and very rare due to human alteration of the Colorado River (Miller 1961) which, among other things, has interfered with its spawning runs up tributary streams (Sigler and Miller 1963). Its larvae seem to be more temperature sensitive than those of other species (Marsh 1985) and the backwater habitats necessary for fry development described by Karp and Tyus (1990) were presumably lacking in the Salton Basin and may have contributed to its apparent rarity in Lake Cahuilla. It migrates great distances (Holden and Wick 1982) and the few individuals represented in the remains probably came from up-river. Sigler and Miller (1963) reported that Indians along the lower Colorado River formerly caught them using dip-nets in waters that receded rapidly, or by shooting them with bow and arrow. All these large fishes could have been taken near shore and captured after their escape was limited by inshore stone weirs described by Wilke (1980).

Striped Mullet

Striped mullet, rare among these remains, were quite abundant in the Salton Sea earlier this century (Dill 1944). Follett (1988) reported finding large numbers of striped mullet otoliths in the Salton Basin. It is a marine species that breeds in offshore waters (Fitch and Lavenberg 1971) and has sporadic appearance in the Colorado River (Follett 1960). Despite reports that it is a bottom feeder (Minckley 1973), its thin and elongate gill rakers are suggestive of filter feeding. Filamentous algae might have been readily available to this herbivore in Lake Cahuilla.

Machete

Only two elements (one a vertebra) of the machete were identified at any of the sites studied. It normally schools in the Gulf of California (Thomson et al. 1979) but has had sporadic appearance in the Colorado River (Follett 1960) and earlier in the Salton Sea, where Dill (1944) found it consumed desert pupfish. It may have consumed the fry and fingerlings of bonytail and razorback suckers over 500 years ago in Lake Cahuilla.

Expected, Unrecorded Species

A large species of the lower Colorado River unrepresented in these studies but potentially a resident of Lake Cahuilla was the flannelmouth sucker. It was an important food fish for Indians (La Rivers 1962). Since flannelmouth suckers do poorly in calm waters of impoundments (Minckley 1973), it would be unlikely to thrive in a calm Lake Cahuilla. Since flannelmouth and razorback suckers hybridize (Hubbs and Miller 1953; Suttkus and Clemmer 1979; Minckley 1983; Buth et al. 1987; Tyus and Karp 1990), distinguishing between their remains could present a considerable challenge. Fertile hybrids, presumably between flannelmouth and razorback sucker, found by Tyus and Karp (1990), provide evidence of the possibility of an introgressive gene pool.

Small fishes (under 9 cm SL) reported by Miller (1961) in the lower Colorado River that do not appear among these remains include three endangered species: the woundfin, desert pupfish, and Gila topminnow. Screens of $\frac{1}{8}$ in. were used in these excavations creating a possible sampling bias because screens with $\frac{1}{8}$ in. and larger mesh miss the remains of small fishes (Fitch 1972; Casteel 1972; Gobalet 1989). Had these small fishes been utilized by Native Americans, they might have been found in coprolites microscopically examined by Wilke (1978) and Farrell (1988).

Summary

Ninety-six percent of the 4421 fish elements identified from 14 archaeological sites along Lake Cahuilla are probably from bonytail and razorback sucker which suggests that Lake Cahuilla was a plankton rich habitat. The razorback sucker probably thrived in the lake and fed upon a plankton bloom resulting from the slow flow and increased surface temperatures of the nutrient rich waters of the Colorado River. Omnivorous bonytail may have extensively exploited the plankton as well. Rare in the lake were piscivorous Colorado squawfish and the euryhaline striped mullet and machete. Small species were undoubtedly present, but not represented among these remains.

Literature review suggests that other large chubs, *G. cypha* and *G. robusta*, as well as the flannelmouth sucker, may have also been present in Lake Cahuilla. Therefore, identifications based on such fragmentary remains should be considered unconfirmed in part because hybridization may have occurred among the chubs and between flannelmouth sucker and razorback sucker. Unfortunately, it is now resources such as these from archaeological sites that are the only ones available for studying the ranges of these vanishing species.

Recommendations to Zooarchaeologists

In reporting the species recovered from an archaeological site be certain to include the zoogeographical and anatomical evidence for identifications and a list of specimens examined in making determinations. It is also advisable to consider the tenuous nature of basing identification on fragmentary remains that may come from species subject to considerable individual variation and possibly hybridization. Qualifying work based on these considerations will enhance the confidence in the identifications. Submit the papers based on the identifications to peer-reviewed journals.

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Materials Examined

Institutional abbreviations are as listed by Leviton et al. (1985) except that unnumbered specimens and those designated KWG are in the collection at California State University, Bakersfield. *Gila bicolor*: OS 7752, OS 7757, CAS 25815, CAS 26302, UMMZ 174438-s(2), KWG 8 skeletons, 136 pharyngeals, 54 basioccipitals; *G. crassicauda*: CAS 18378, KWG 14 partial pharyngeals; *G. cypha*: UMMZ 179577-5, 178667; *G. elegans*: AMNH 46106, CAS 25865, CAS 66037, CAS 66038; *G. robusta*: AMNH 46113, AMNH 47091, AMNH 47092, AMNH 47093, AMNH 47094, AMNH 47095, AMNH 47096, AMNH 47097, AMNH 47098, AMNH 47099, CAS 25850, CAS 25851, UMMZ 179580, UMMZ 182502; *Ptychocheilus lucius*: CAS 66217; *P. grandis*: KWG 243, skeleton; *P. oregonensis*: KWG 347, KWG 404, KWG 454; *Xyrauchen texanus*: AMNH 30848, CAS 66229, CAS 66231, LACM 43613-1; *Catostomus catostomus*: KWG 453, one skeleton; *C. fumeiventris*: 2 skeletons; *C. latipinnis*: UMMZ 178628, UMMZ 178690, UMMZ 179567; *C. macrocheilus*: KWG 349, KWG 353, KWG 366, one skeleton; *C. occidentalis*: KWG 277, KWG 240; *C. tahoensis*: KWG 350, KWG 363, 7 skeletons; *Chasmistes cujus*: KWG 346, KWG 399, KWG 351; *Erimyzon tenuis*: 2 skeletons; *Ictiobus bubalus*: KWG 364, KWG 361; *Elops affinis*: KWG 205, KWG 294; *Mugil cephalus*: KWG 360, KWG 347.

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A Survey of the Trematoda (Platyhelminthes: Digenea) Parasitic in Green Turtles, *Chelonia mydas* (L.) from Hawaii

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Abstract.—Ten Hawaiian green turtles (*Chelonia mydas*) with fibropapilloma tumors were collected from three islands (Lanai, Maui, Oahu) and examined for digenetic trematode parasites. A total of 232 worms were recovered representing six genera (*Angiodictyum*, *Carettacola*, *Hapalotrema*, *Learedius*, *Polyangium*, *Pyelosoma*). The prevalence of infection does not appear to be affected by the size, sex, or locality of host.

The Hawaiian green turtle population is geographically isolated. The number of productive females has been reduced to only 100–300 annually (Balazs 1980). Neoplasms identified as fibropapillomas are being commonly found on these turtles throughout the Hawaiian Islands. Up to 10% of the nesting females tagged each year at the breeding colony of French Frigate Shoals have these epithelial growths. The papillomas range from a few millimeters to 30 cm in diameter (Fig. 1) (Dailey and Balazs 1987). These disfiguring growths in turtles can result in reduced vision, disorientation, blindness, and physical obstruction to normal swimming and feeding. Consequently, many animals are found on the beach unable to survive in nature. The etiology of fibropapillomas in green turtles remains unknown, however, the presence of trematode ova within the fibrotic portion of the lesions indicates it could be of digenetic trematode origin (Dailey and Balazs 1987). This survey was carried out to document the trematodes parasitizing the Hawaiian green turtles and ascertain the possible effect, if any, of these parasites on the population.

From 1986 to 1988, 10 green sea turtles were collected as stranded animals from the islands of Lanai, Maui, and Oahu. The turtles were brought to the National Marine Fisheries Service holding facilities at Kuwalo Basin, Honolulu, Hawaii. Upon determination that the turtles would not survive they were euthanized and necropsied.

The literature on parasites from sea turtles is extensive and scattered. The taxonomic classification and host parasite names used in this study have generally followed those of Yamaguti (1971), Ernst and Ernst (1977), and Blair (1986).

This is the first survey of digenetic trematodes infecting the Hawaiian green turtle population.

Materials and Methods

A thorough examination for parasites was carried out on the lungs, liver, heart, stomach, intestine, and bladder. Worms were placed in tap water and refrigerated

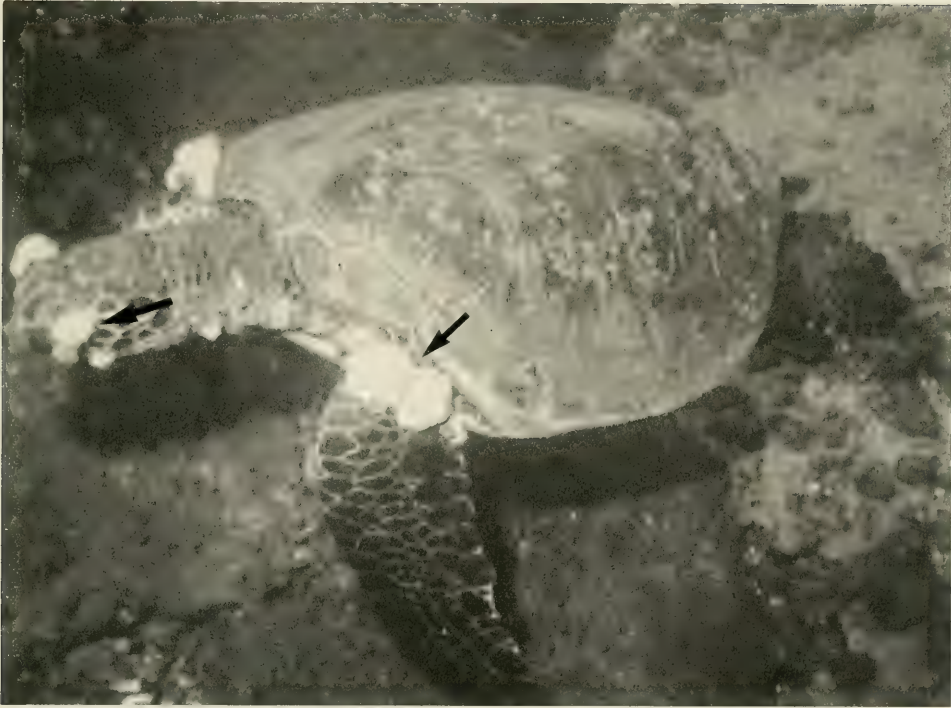


Fig. 1. Fibropapillomas on the eyes and flipper of the green turtle, *Chelonia mydas* from Hawaii.

overnight for egg expulsion, fixed in alcohol-formalin-acetic acid (AFA) solution for two days, then transferred to 70% ethyl alcohol for storage. Whole mounts used for identification were stained in Semichon's acetocarmine, dehydrated in a graded ethanol series, and mounted for examination.

Voucher specimens were deposited at the Institute of Parasitology, California State University, Long Beach, California.

Results

Ten turtles ranging from 46.0 to 86.1 cm in size, all with tumors, were found infected with a total of 232 worms comprising six genera and seven species of digenetic trematodes (Table 1).

Intestinal Fauna

Angiodictyidae Looss, 1902

Fourteen specimens of *Polyangium linguatula* (Looss, 1899) Looss 1902 were recovered from the small intestine of four turtles (40%). Turtles from the islands of Oahu (3) and Lanai (1) shared the total number of this species collected during the study (Table 1).

This is the first report of this species from *C. mydas* in the eastern Pacific. Previous reports are from Puerto Rico (Dyer et al. 1991), Australia (Blair 1986),

Table 1. Hawaiian green turtles infected with trematode parasites.

Field no.	Host carapace length (cm)	Sex	Location	Parasite	Species/ host	Total no. worms recorded
5/05/86	66.8	Nd	Haleiwa, Oahu	<i>Learedius learedi</i>		6
				<i>Hapalotrema</i> sp. (A)	3	7
				<i>Polyangium linguatula</i>		2
6/24/87	58.6	Nd	Keomaku, Lanai	<i>Hapalotrema</i> sp. (A)		7
				<i>Polyangium linguatula</i>	3	1
				<i>Angiodictyum longum</i>		2
7/10/87	46.0	Nd	Chuns Reef, Oahu	<i>Hapalotrema</i> sp. (A)		8
				<i>Hapalotrema</i> sp. (B)	2	2
8/09/87	55.0	F	Kailua Bay, Oahu	<i>Hapalotrema</i> sp. (A)	1	3
8/16/87	55.0	F	Kailua Bay, Oahu	<i>Hapalotrema</i> sp. (A)		20
				<i>Hapalotrema</i> sp. (B)	2	14
10/25/87	83.2	M	Pearl Harbor, Oahu	<i>Hapalotrema</i> sp. (A)		8
				<i>Hapalotrema</i> sp. (B)	2	2
11/20/87	62.2	F	Kaneohe Bay, Oahu	<i>Angiodictyum longum</i>		2
				<i>Polyangium linguatula</i>	2	2
12/20/87	66.2	F	Chuns Reef, Oahu	<i>Angiodictyum longum</i>		5
				<i>Caretta hawaiiensis</i>	5	3
				<i>Hapalotrema</i> sp. (A)		5
				<i>Learedius learedi</i>		4
				<i>Polyangium linguatula</i>		9
1/25/88	83.1	F	Kaneohe Bay, Oahu	<i>Caretta hawaiiensis</i>		10
				<i>Learedius learedi</i>	3	43
				<i>Pyelosoma cochlear</i>		19
5/04/88	86.1	Nd	Kahului Bay, Maui	<i>Caretta hawaiiensis</i>		17
				<i>Hapalotrema</i> sp. (A)	3	5
				<i>Learedius learedi</i>		26
					Total	232

Brazil (Teixeira de Freitas and Lent 1938), and Egypt (Looss 1902). The worms studied during this survey were much larger than those previously described (Table 2). Also, no fine spines were found on the cuticle, the testes were ovoid, not irregular in shape, and the genital pore was more anteriorly placed than in the Australian specimens.

Nine specimens of *Angiodictyum longum* Blair 1986 were recovered from the small intestine of three turtles, two from Oahu and one from Lanai (Table 3). This species was described by Blair (1986) from *C. mydas* taken from Badu Island, Torres Strait, Queensland, Australia. He differentiates this species from the other three (*A. parallelum* (Looss, 1901) Looss 1902; *A. posteroventralum* Challopadyaya, 1972; *A. glossoides* Blair 1986) members of the genus by placement of genital pore and anterior extension of vitellaria. The Hawaiian specimens differed from the type material in smaller size ($4.75\text{--}6.25 \times 1.0\text{--}1.5$ mm) and in possession of a muscular expansion at the posterior end of the esophagus just anterior to the cecal bifurcation.

This report extends the range of this species from Australia, India, and Egypt to the eastern Pacific.

Table 2. Comparison of Hawaiian specimens of *Polyangium linguatula* to other geographical sites.

	Measurement of specimens from:			
	N = 10 Hawaii	N = 3 Australia	N = 9 Egypt	N = 1 Brazil
Body length	9.2-13.7 (11.7)	4.3-7.9 (6.6)	4.3-7.9 (6.3)	7.74
Body width	1.8-2.1 (1.9)	1.3-1.5 (1.4)	1.0-1.6 (1.2)	1.63
Oral sucker length	0.21-0.27 (0.24)	0.16-0.18	0.11-0.15 (0.14)	0.16
Oral sucker width	0.34-0.38 (0.36)	0.23-0.24	0.15-0.23 (0.17)	0.2
Esophagus length	2.9-3.3 (3.1)	1.72-1.76	0.67-1.75 (1.26)	1.33
Anterior testes length	0.88-0.99 (0.93)	0.33-0.42 (0.37)	0.34-0.56 (0.46)	0.51
Anterior testes width	0.65-0.79 (0.72)	0.36-0.48 (0.4)	0.39-0.60 (0.50)	0.51
Posterior testes length	0.86-1.02 (0.92)	0.22-0.4 (0.34)	0.38-0.65 (0.51)	0.43
Posterior testes width	0.70-0.80 (0.75)	0.42-0.5 (0.47)	0.41-0.56 (0.49)	0.52
Ovary length	0.27-0.37 (0.33)	0.18-0.25 (0.22)	0.19-0.3 (0.24)	0.26
Ovary width	0.24-0.26 (0.25)	0.2-0.24 (0.22)	0.15-0.24 (0.19)	0.21
Eggs in utero length	0.092-0.12	0.071-0.077	0.079-0.091	0.072-0.082
Eggs in utero width	0.057-0.065	0.044-0.046	0.044-0.064	0.043-0.045
Reference	This paper	Blair (1986)	Looss (1899, 1902)	Teixeira de Freitas and Lent (1938)

Table 3. Prevalence of parasites in Hawaiian green turtles.

Parasite	No. host	% Host	No. worms recorded	% of total worms	Infection site
<i>Angiodictyum longum</i>	3	30	9	3.8	intestine
<i>Carettacola hawaiiensis</i>	3	30	30	12.9	liver
<i>Hapalotrema</i> sp. (A)	7	70	36	15.5	heart
<i>Hapalotrema</i> sp. (B)	3	30	18	7.7	heart
<i>Learedius learedi</i>	4	40	79	34.0	heart
<i>Polyangium linguatula</i>	4	40	14	6.0	intestine
<i>Pyelosoma cochlear</i>	1	10	19	8.1	urinary bladder

Urinary Bladder Fauna

Pronocephalidae Looss, 1902

One turtle from Kaneohe Bay, Oahu, was found infected with 19 specimens of *Pyelosoma cochlear* Looss, 1899. This parasite was originally described from the urinary bladder of *C. mydas* from Egypt. It has also been reported from the same host from Puerto Rico (Dyer et al. 1991) and Panama (Oguro 1936). Five other intestinal species are currently acknowledged in this genus (*P. longicaecum* Luhman, 1935; *P. posterorchis* Oguro, 1936; *P. parvum* Prodhoe, 1944; *P. amblyrhynchi* Ruiz, 1946; *P. renicapite* (Leddy, 1856) Poche, 1926). The diagnosis of the genus Pronocephalidae by Yamaguti (1971) was amended by Threlfall (1979) to include *P. renicapite*.

All *P. cochlear* found in this study were small and sexually immature.

Blood Vascular System Fauna

Spirorchiiidae Stunkard 1921

Seventy nine specimens of *Learedius learedi* Price, 1934 were recovered from the hearts of four turtles. Over one-half (43) of these were collected from one animal found stranded at Kaneohe Bay, Oahu (Tables 1, 3). This parasite appears to be ubiquitous as it has been reported from Puerto Rico (Dyer et al. 1991), Panama (Caballero et al. 1955), Florida (Nigrelli 1941), Grand Cayman, British West Indies (Greiner et al. 1980), Bermuda (Rand and Wiles 1985), and Australia (Blair 1979). *Learedius learedi* was originally described from the "edible turtle" or "common turtle" in England in 1862. Smith (1972), in a review article, suggests that the turtle was a *C. mydas* that had been imported into the United Kingdom for turtle soup.

We found no morphological differences between our specimens and those of the original description.

Carettacola hawaiiensis

Thirty specimens of *Carettacola hawaiiensis* were recovered from the liver vessels of three turtles (two from Oahu, one from Maui) (Table 1).

Carettacola was a monotypic genus (*C. bipora*) described by Manter and Larson (1950) from the intestinal washings of a loggerhead turtle (*Caretta caretta*) captured in Florida. The authors state that the worm was "probably originally from some blood vessel" (Smith 1972).

The findings in this study document the first report of a spirorchid blood fluke from a marine turtle liver.

Hapalotrema spp.

Two undescribed species of the genus *Hapalotrema* (listed as A, B in Table 1) were found to be the most prevalent (70% for *Hapalotrema* sp. A) worm in this study (Table 3). The genus *Hapalotrema* contains six previously described species (*H. loossi* Price, 1934; *H. mistroides* (Manticelli, 1896) Stiles and Hassall, 1908; *H. orientale* Takeuti, 1942; *H. synorchis* Luhman, 1935; *H. mehrai* Rao, 1976; *H. postorchis* Rao, 1976) all found in the hearts of turtle hosts. *Hapalotrema loossi*, *H. mehrai* and *H. postorchis* are the only species in the genus that have been previously reported from *C. mydas*. The specimen from that report was *H. loossi*, collected from India (Rao 1976). The others (*H. mistroides*, *H. synorchis* and *H. orientale*) are reported from loggerhead (*C. caretta*) and leatherback (*Eretmochelys squamosa*) turtles respectively (Smith 1972).

Discussion

Parasites from *Chelonia mydas* have been previously listed by other authors (Blair 1979; Caballero et al. 1955; Dyer et al. 1991; Greiner et al. 1980; Glazebrook et al. 1989). However, this is the first study of this kind on the Hawaiian green turtle population. The prevalence of infection does not appear to be affected by size, sex, or locality. The distribution of infection by various species appears to be random, as shown by the two turtles from Chuns Reef, Oahu, in Table 1. In number 7/10/87, the turtle was 46 cm in carapace length and was infected with both species of *Hapalotrema* (A and B). In number 12/20/87, a larger turtle (66.2 cm) also collected at Chuns Reef, Oahu, the authors recovered five different genera of trematode parasites; however, only one species (*Hapalotrema* (A)) of the genus *Hapalotrema* was present. Given the gaps of knowledge in the green sea turtle life history, which involves migrations to various breeding and foraging habitats, this finding is not surprising. It is also not surprising that the complete life cycle for a marine spirorchid, infecting sea turtles, has, to date, not been elucidated, given the complexity of marine ecosystems. The traditional cycle for spirorchids in fresh water turtles that involve a snail intermediate host (Smith 1972) may not apply here. Studies to date on snails from infected green turtle habitats have been negative for any spirorchid trematode larvae (Greiner et al. 1980; MDD, this study).

The spirorchid findings in this study conform to the survey reports previously published. Glazebrook et al. (1989) working on sea turtles from the Great Barrier Reef in Australia, summarized the findings of cardiovascular flukes found in three genera of turtles (*Chelonia*, *Eretmochelys*, *Caretta*). He lists eight genera of digenetic trematodes of the family Spirorchiidae reported from the cardiovascular system of turtles, the most common site being the heart. The Hawaiian green turtles in this study were found to have three genera (*Learedius*, *Hapalotrema*, *Carettacola*) of cardiovascular flukes, two of which inhabited the heart and one the liver. The microscopic changes caused by these parasites in the host system were also outlined by Glazebrook et al. (1989). They state that "multiple diffuse egg granulomas were a prominent feature of most organs, the spleen and lungs being predilection sites." Similar findings were observed during this study where

large egg masses were recovered from the lungs and liver. An acute and chronic vasculitis accompanied by metastasis of trematode eggs was found by Wolke et al. (1982) while looking at loggerhead turtles from Florida to Massachusetts. These authors also found trematode eggs and associated inflammatory response in the gut, liver, spleen, kidney, heart, stomach, and testes. This and other reports of parasite egg distribution throughout the body of the sea turtle via its blood vascular system would help explain the finding of eggs in fibropapilloma tumors. Whether or not the response to these eggs by the host animal causes these tumors is still not clear. However, the consistent finding of a large number and variety of trematode worms in Hawaiian sea turtles would indicate that these parasites may play a role in the general health and subsequent survival of members of this population.

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RESEARCH NOTE

Redescription of *Ophryotrocha platykephale* Blake (Polychaeta, Dorvilleidae) from the Guaymas Basin Hydrothermal Vents

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While participating in the 1988 expedition to the Guaymas Basin hydrothermal vents, one of us (V. S. W.) observed and collected live specimens of a dorvilleid polychaete that resembled *Ophryotrocha platykephale* Blake, 1985 described from the same locality. The specimens appeared to differ from *O. platykephale* in the development of the parapodial cirri. Blake (1985) illustrated the parapodia with reduced dorsal cirri and long ventral cirri, whereas the specimens from the Guaymas Basin possessed well-developed dorsal cirri and very small ventral cirri. Reexamination of Blake's specimens revealed that the illustration of the parapodia of *O. platykephale* is incorrect, and that the new specimens from the Guaymas Basin belong to the same species. This error has been noted by Blake and Hilbig (1991).

This paper presents a redescription of *Ophryotrocha platykephale*, based on specimens kindly provided by Blake and five additional new specimens from the Guaymas Basin. The latter are complete and of a larger size, resulting in additions to the description of the posterior end and some additional morphological details. Information about the biology of these worms observed during the dives is also presented.

Ophryotrocha platykephale Blake, 1985

Material examined.—Holotype and five paratypes (USNM 81837-8). Additional material: Guaymas Basin hydrothermal mounds, DSRV *Alvin* dive 1976, 15 Feb 1988, 2000–2020 m, tube core 1, 5 specimens (USNM 136558). Several specimens from private collections of Dr. J. A. Blake.

Redescription.—Length up to 40 mm, width up to 2.5 mm including parapodia. Body dorsoventrally compressed, with rugged appearance in posterior half, slightly tapering towards pygidium. Colour in life and in alcohol: opaque white. Prostomium dorsoventrally flattened, wider than long, with cirriform, distally tapering antennae and palps of equal length; eyes absent (Fig. 1A). Ventral mouth surrounded by thickened lips projecting laterally (Fig. 1B). Peristomium consisting of one ring.

Parapodia uniramous, projecting distinctly from body, with pre- and postsetal

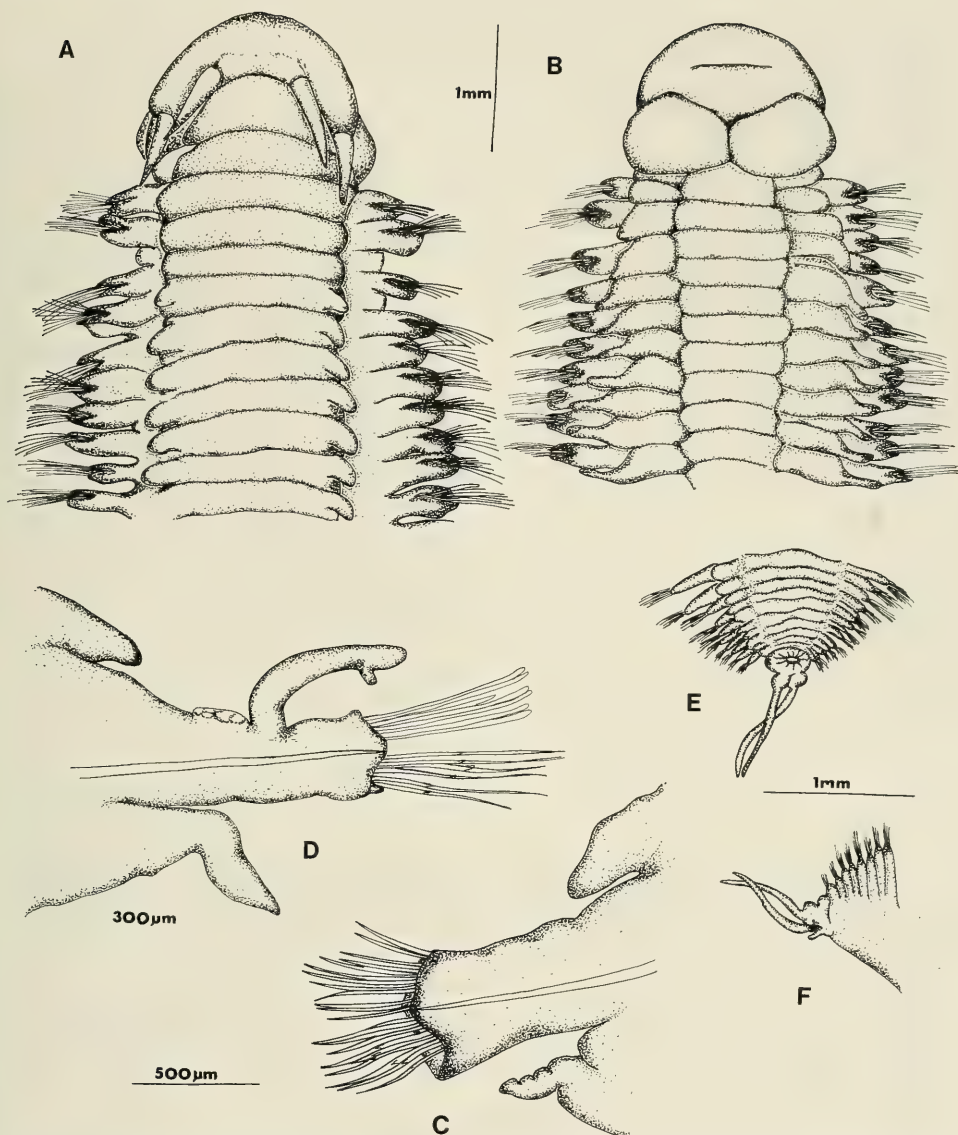


Fig. 1. *Ophryotrocha platykephale* Blake, 1985. A, anterior end, dorsal view. B, anterior end, ventral view. C, tenth parapodium, anterior view. D, midbody parapodium, anterior view. E, pygidium, ventral view. F, pygidium, lateral view.

lobes; short and rounded in anterior 14 to 15 setigers (Fig. 1C), gradually becoming elongate in subsequent setigers. Dorsal cirri first occurring in setigers 17 to 19, inserted subdistally on parapodia; inconspicuous in anteriormost setigers, gradually becoming longer and digitiform; in posterior half of body distally bifid, with short ventral subdistal projection and dorsal fusiform tip, sometimes resembling a separate distal article (Fig. 1D). Ventral cirri short, retractile, present from setiger 3 to near end of body. Dorsal branchiae present from setiger 14; short, digitiform, about as long as lobes of short anterior parapodia. Ventral branchiae present from

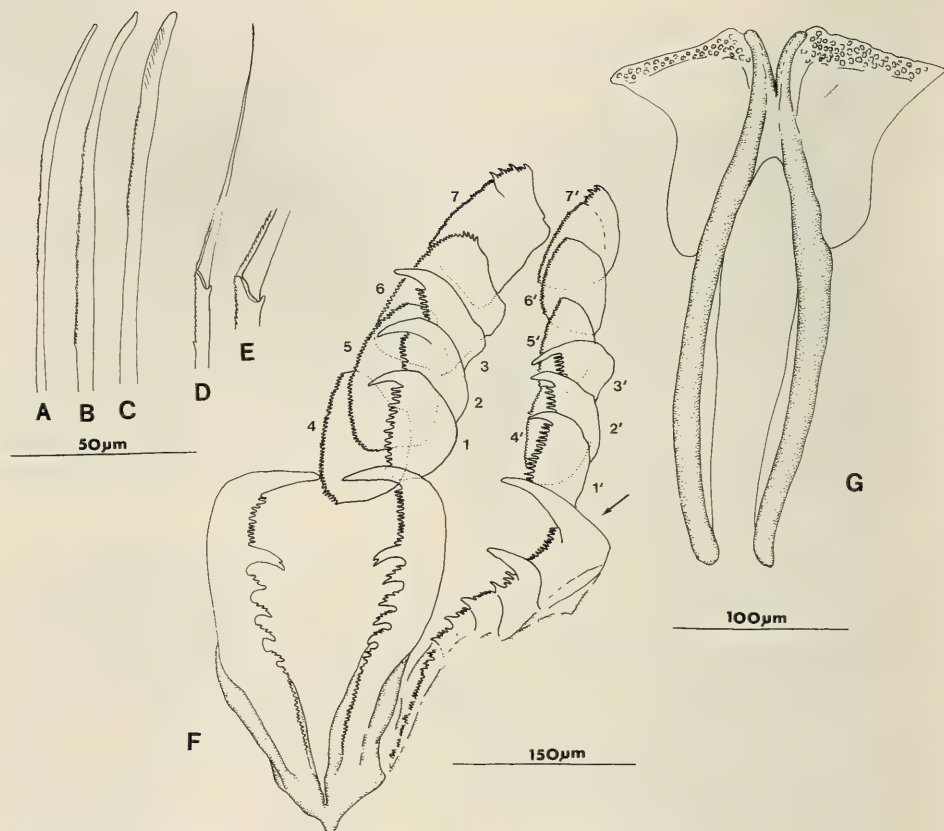


Fig. 2. *Ophryotrocha platycephale* Blake, 1985. A, simple seta, setiger 1. B, simple seta, setiger 5. C, simple seta, midbody. D, compound seta. E, detail of compound seta (not to scale). F, maxillae. 1-7: free denticles; 1'-7': free denticles of replacement jaws; arrow: forceps of replacement jaws. G, mandibles.

setiger 2, fully developed in setiger 4; longer than dorsal branchiae, foliaceous, distally tapering; largest in middle and posterior setigers, decreasing in last ten setigers. Large parapodial glands present between dorsal cirrus and dorsal parapodial base (Fig. 1D).

Setae arranged in single vertical row; dorsal fascicle with about 14 simple spines, ventral fascicle with approximately 16 compound spinigers; number of setae per fascicle highest in anterior setigers. Simple setae distally flattened and subdistally serrated; in anterior four parapodia slender, curved, slightly tapering (Fig. 2A); in following setigers gradually becoming almost twice as wide, straight, blunt-tipped (Fig. 2B, C). Compound spinigers with distally serrated shafts and long blades with basal serrations (Fig. 2D, E). Single internal acicula present. Pygidium rounded, with two deciduous, long, slender dorsal cirri and a small, inconspicuous ventral stylus. Anal pore dorsal, surrounded by papillae (Fig. 1E, F).

Maxillae with large P-type forceps and 7 pairs of free denticles arranged in superior and inferior rows on each side (Fig. 2F). Forceps basally serrated, with large teeth with serrated upper edge medially, and bifid lower fang, subdistal serrations, and large upper fang apically. Superior free denticles (D1-D3) elongate,

rounded plates with anterior main fang and coarsely serrated cutting edge; denticles of inferior row (D4–D7) more delicate rounded to rectangular plates with finely serrated cutting edge; D5–D7 with anterior set of slightly coarser dentitions, most distinct on D7. Forceps in jaw replacement (Fig. 2F) with distinct fusion lines, suggesting 5 major denticles apically and numerous smaller teeth basally. Mandibles elongate, slightly curved rods, distally fused; with narrow wings along inner margins and broad, transparent, roughly triangular lateral projections anteriorly; cutting edge smooth, unsclerotized (Fig. 2G).

Biology.—From the DSRV *Alvin*, specimens of *O. platykephale* were observed swimming among a large colony of the ampharetid *Amphisamytha galapagensis*. The specimens exhibited vertical brusque movements. The ampharetid colonies, which were seen to extend for several square meters, consisted of simple or branched tubes protruding vertically from the sediment. Only parts of the ampharetid's branchiae could occasionally be seen. The substrate was a seep site with the surface warmed by hot water percolating slowly upwards, but away from the chimneys (black or white smokers) and the *Riftia* colonies.

Remarks.—*O. platykephale* is only the second species of *Ophryotrocha* known to change setal shape after the first few anterior setigers. This condition was first described for *O. hadalis* by Jumars (1974). Hilbig and Blake (1991) describe a number of deep-sea *Ophryotrocha* species from the U.S. Atlantic slope and rise, most of which have slightly shortened and thickened setae in the anteriormost setigers; however, the differences in setal shapes are not as pronounced. Hilbig and Blake suggest that deep-sea *Ophryotrocha* form a closely related group within the genus, possibly sharing ancestors with the deep-sea genus *Exallopus* Jumars. This hypothesis is now confirmed by the addition of another deep-sea species to this group.

O. platykephale is also related to a number of species that possess several atypical characters, such as large body size, well-developed prostomial and parapodial appendages, numerous setae per fascicle, and greatly reduced ciliation (Hilbig and Blake 1991). The species is easily distinguished from its congeners by the presence of branchiae, the shape of the setae, and the absence of dorsal cirri in anterior setigers.

Distribution.—Guaymas Basin, hydrothermal ventfields in mud, 2000–2020 m.

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COVER: Nest and young of the California Least Tern. Photograph by Charles T. Collins. (Page 49).